BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-023284
Article Type:	Research
Date Submitted by the Author:	08-Apr-2018
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Keywords:	Youth, Biological maturation, Skeletal age, Anthropometrics, Sports injury, Mature height

Sports Injuries Aligned to Predicted Mature Height in Highly Trained Youth Athletes: Cohort study

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Word count = 3445

ABSTRACT

Objectives: To investigate the association of maturity status with injury incidence in highly trained Middle-Eastern youth athletes.

Design: Prospective cohort study

Setting: Four consecutive seasons ranging from 2010 to 2014 at the Aspire Academy for Sports Excellence, Qatar.

Participants: Male athletes (age range: 11–18 y) representing four sporting disciplines were enrolled and grouped into two categories: individual sports (athletics and fencing) and racquet sports (squash and table tennis).

Outcome measures: Athletes' anthropometric characteristics were assessed to calculate age at peak height velocity (APHV) and total years from PHV. Participants predicted mature heights (PMHs) were collected and categorized into four PMH quartiles. Consenting athletes had wrist and hand radiographs taken for assessment of skeletal age (SA), using Fels method. Early and late maturers were those with an SA of >1 y either older or younger than their chronological age (CA), respectively.

Results: For the sample (n = 67) across all sport groups, 43 (64%) athletes had one or more injuries: a total of 212 injuries, or 4.9 injuries per registered athlete. Survival analysis using Cox regression of maturity status found that early maturing athletes had a two-fold greater risk of injury over time compared to late maturers (hazard ratio [HR]; 2.04, 95% CI 1.15–3.61, P = 0.015). PMH was associated with injury risk (HR 1.05, 95% CI 1.01–1.08, P = 0.006).

Compared to the PMH for participants in the 1st quartile (<176 cm), athletes in the 4th quartile (≥ 184 cm) had a higher (up to 2-fold) injury risk (HR 2.41, 95% CI 1.42–4.08, P = 0.001).

Racquet and individual sports involved a similar injury risk (HR 1.14, 95% CI 0.86–1.52, P = 0.37).

Conclusions: Early maturation and PMH gradient were significant predictors of injury in youths.

Key words: youth, biological maturation, skeletal age, anthropometrics, sports injury, mature height

Strengths and limitations of this study

- The first longitudinal study to assess the anthropometric characteristics and biological maturity status as injury risk factors in Middle-Eastern youth athletes.
- The participants were highly trained male adolescent athletes.
- Measurement of maturity and growth were found to be at moderate-to-high risk of bias.
- SA as an indicator of maturation, has major limitations in expense and minimal radiation and lack of knowledgeable staff for assessment protocols and the interpretation of results.

INTRODUCTION

The range of somatic and biological maturity in individuals of the same chronological age (CA) is large [1]. Such observations are derived from correlational and multivariate studies that compare young individuals of the same age who are at both extremes of the maturity range [2]. Therefore, the assessment of maturity is an important consideration when dealing with adolescent athletes on a longitudinal basis. Further, understanding the cause of disease and injury is vital in predicting and preventing injury [3].

In young athletes, the demands of their chosen sport are superimposed on normal growth and maturation. A literature review revealed that there is a greater susceptibility to injury during certain periods of growth [4–6]. Indeed, the association between an increased prevalence of injuries and the adolescent growth spurt has long been recognized [7,8]. Mismatched rapid growth in the long bones relative to muscular lengthening may disrupt structure, neuromuscular function, and physical performance [9].

Deehan et al. [10], state that an increased participation in sports predisposes the immature skeleton to injury. Furthermore, participation in high intensity sport entails an inherent risk of sports-related injuries, and this is heightened at various stages of growth and maturation [11]. Maturation induces profound changes in the skeletal, neuromuscular, and tendinous systems of young athletes [12] and mismatches in biological maturity may create competitive inequality and increase the risk of injury [13]. Le Gall et al. [14], further point out that injury rates generally increase with increasing CA. However, CA is a poor indicator of biological maturity [15]; moreover, Ardern et al. [16], report that chronological age alone is an unreliable indicator of skeletal maturity. Skeletal age (SA) is generally accepted as the most accurate method of assessing biological maturity [6,17], by identifying critical periods of development; it also offers a rational method for monitored age-specific training. Before initiating any program for mitigating sports injuries, the magnitude of the problem must be identified and the extent of the injury defined in terms of incidence and severity [18].

A number of studies have been conducted involving injuries in adolescent footballers; conversely, few studies have focused on injuries in non-footballer adolescent athletes in high performance sporting environments [19]. Studies of anthropometric characteristics and biological maturity status as injury risk factors in Middle-Eastern youths are also limited, highlighting the need for more research in this area. Therefore, the purpose of the present study was to investigate injury incidence according to biological maturity in highly trained youth athletes based at a Middle Eastern Sports Academy.

METHODS

Sixty-seven highly trained adolescent athletes (age range 11–18 y) representing athletics and racquet sports (table tennis and squash) from a Middle Eastern sports school were included in this four-year study. A prospective, longitudinal cohort design was used and included separate observation periods over four consecutive seasons (20010–2011, 2011–2012, 2012–2013, and 2013–2014), i.e., school years, which lasted from the beginning of September until the end of June (~40 weeks). Participant maturity assessments included both anthropometric measurements, collected three times a season, and SA assessments using Fels method completed once, at the start of every season. Medical screening was performed at the beginning of each season to determine health and injury status. All selected athletes had clearance from a physician to participate in their respective sport. Written informed consent was sought and obtained from parents and assent from all participants. The study was part of a general sports science provision to the sports academy, and all procedures were reviewed and granted by the Institutional Review Board (IRB) for Human Subjects and conformed to the recommendations of the Declaration of Helsinki.

Participants involvement

Figure 1 shows the flow of participants in the study over consecutive seasons. A total of four sporting disciplines were analysed, grouped into two categories: athletics and fencing and racquet sports (squash and table tennis). This classification was based on specific sport characteristics and injury risk [20,21]. Inclusion criteria were as follows: (1) the athlete had to be enrolled in the sports school during at least one full school year; (2) athletes with injuries in previous seasons were not excluded from this study, but injuries present at the beginning of the observation period were not included in statistical analyses; and (3) injuries that were not sustained in the context of the sports program or data related to sickness or other general medical conditions were not used for further analysis.

<<<Insert Figure 1 here>>>

Injury data collection

All injuries were assessed by a physical therapist (AR) with experience of working within youth sport. Data from medical records were used to document all sports related injuries during the study. Each sporting discipline had a dedicated full-time physiotherapist and a full-time employed medical doctor at the sports academy. The medical record used an injury reporting system based upon the football injury reporting system [22] and the Sport Medicine Diagnostic Coding System [23]. Information was gathered concerning all injuries related to sports activity, including several related variables (e.g. type, location, affected structure, mechanism [acute vs. overuse], time loss, severity, and date of injury).

Somatic maturation and anthropometric measurements

Anthropometric measurements were initially carried out on all participants on a three monthly basis along with an estimation of the age at peak height velocity (APHV) as a relative indicator of somatic maturity and representing the time of maximum growth in stature during adolescence [1]. To ensure that the outcome measures remained consistent and reliable, every effort was made to ensure that measurements were taken at approximately the same time of the season. Measurements were collected by qualified practitioners from the International Society for the Advancement of Kinanthropometry (ISAK) and included stretch stature (± 0.1 cm Holtain Limited, Crosswell, UK).

The predicted mature height (PMH) of all participants were collected and categorized into four PMH quartiles (Q1–Q4: Q1, <176 cm; Q2, 176–180 cm; Q3, 180–184 cm; Q4, ≥184 cm). The athletes were then divided into three maturity groups (late, normal, or early maturing) based on the mean ± 1.0 year of the APHV of the total sample (late, APHV > mean + 1.0 y; normal, APHV within mean ± 1.0 y; early, APHV < mean – 1.0 y). Years from peak height velocity (maturity offset value: CA – maturity offset) was calculated by subtracting the CA at the date of injury from the age at estimated peak height velocity.

Skeletal maturation assessment

Each year consenting athletes had a radiograph of the left wrist and hand, a convenient area to examine, and a more accurate method for the assessment of SA [9], using the Fels method [6,24] which has an advantage over other methods [25]. Maturity status, defined by the difference between CA and SA was calculated and classified into four categories: late, normal, early, and mature athletes. Late referred to an SA that was younger than CA by more than 1.0 y, athletes with a normal pattern of maturity had an SA that was within 1.0 y of CA, early referred to an SA that was older than CA by more than 1.0 y, and the closure of growth plate determine skeletally mature athletes.

Definition of injury

Injuries were recorded as a physical complaint requiring the attention of medical staff, which occurred during sports training, strength and conditioning training or during competition. Injuries were divided into time-loss (TL) injuries and no time-loss (NTL) injuries. A clinical examination and/or treatment of an athlete which did not result in a full training session or competition being missed was described as a "medical attention" with NTL injury. A clinical examination and/or treatment of an athlete resulting in a training session or competition being missed the following day(s) was labelled as a TL injury [22]. A traumatic injury was defined as any injury resulting from a specific and identifiable mechanism, including contact and non-contact circumstances with acute onset. Overuse injuries were defined as injuries resulting from insidious onset without a recognisable mechanism. Injury severity was defined, based on days of absence from usual sport participation, as slight (1 d or less), minimal (2–3 d), mild (4–7 d), moderately serious (8–28 d), serious (>28 d up to 6 months) or long-term (>6 months) in accordance with [26].

Statistical Analysis

Data were analysed using statistical software (Stata Corporation, College Station, Texas). Descriptive statistics were presented as frequencies and proportions (%), and incidence rates were expressed as the number of injuries/number of registered athletes. To examine the role of growth status and maturity with the onset of injuries, a univariate Cox regression survival analysis was performed after accounting for repeated visits of some athletes over the four seasons. Hazard ratios (HR) with 95% confidence intervals (CIs) were reported for each factor. Kaplan-Meier curves were plotted for SA groups and time to injury over a season. Where appropriate, 95% CIs are presented. The alpha level of significance was set at 5%.

RESULTS

Throughout the study period, 67 athletes were enrolled. Table 1 presents the anthropometric characteristics of participants and their maturity status. From these participants, 43 (64%)

reported one or more injuries adding up to 212 injuries in total. Over the four seasons, the injury rate observed was 4.9 per registered athlete.

Table 1. Anthropometric characteristics (mean ± SD) of participants according to maturity status

	Late	Normal	Early
	(n = 4, 6.0%)	(n = 59, 88.1%)	(n = 4, 6.0%)
CA (years)	13.3 ± 1.1	12.3 ± 1.0	12.1 ± 0.5
Years from PHV	-2.4 ± 1.2	-1.6 ± 1.1	-0.1 ± 0.9
APHV (years)	15.8 ± 1.5	13.9 ± 0.5	12.2 ± 0.9
PMH (cm)	181.6 ± 17.1	179.4 ± 4.9	188.4 ± 3.5
% PMH (%)	85.0 ± 3.0	85.0 ± 4.0	90.0 ± 4.0
SA (years)	11.8 ± 0.5	12.8 ± 1.5	12.7 ± 1.8

CA: chronological age; APHV: age at peak height velocity; PMH: predicted mature height; SA: skeletal age; SD: standard deviation

Skeletal age: maturity status distribution and injury risk

Among all participants (n = 67), 4% were classified as late maturers, 33% as normal, 41% as early and 22% as skeletally mature. The overall injury free survival analysis of maturity status using SA assessment indicated that early maturing athletes had a two-fold higher risk of injury over a season compared to late maturing athletes (HR 2.04, 95% CI 1.15–3.61, P = 0.015; Figure 2). There was a trend that early maturing athletes had a greater risk of injury over a season compared to normal athletes (HR 1.62, 95% CI 0.99–2.65, P = 0.053), but this was only marginally significant. However, injury risk among late and fully mature athletes did not differ from normal maturers.

<<<<Insert Figure 2 Here >>>>

Somatic maturation and anthropometric measurements: distribution and injury risk

Using anthropometric measurements, among all participants (n = 67), 6.0% were classified as late maturing, 85.8% as normal, and 6.0% as early. Classification of participant maturity status (late, normal, and early) according to age at PHV (APHV) was not significantly associated with overall injury incidence in this cohort of highly trained Middle-Eastern youth athletes. Older PHVs were marginally associated with higher injury risk, but this was not statistically significant (HR 1.11, 95% CI 0.99–1.23, P = 0.067).

Both PMH (cm), and %PMH (%) were found to be associated with injury risk (HR 1.05, 95% CI 1.01–1.08, P = 0.006, and HR 1.03, 95% CI 1.00–1.06, P = 0.026), respectively. When compared to participants in the 1st quartile for PMH (<176), athletes in the 4th quartile (≥184 cm) had a two and half times greater risk of injury (HR 2.41, 95% CI 1.42–4.08, P = 0.001) over a season.

No significant differences were observed in the injury risk between racquet sports (n = 30) and individual sports athletes (n = 37; HR 1.14, 95% CI, 0.86–1.52, P = 0.37).

DISCUSSION

The present investigation was carried out to examine injury incidence according to maturity status. Biological maturity status and height gradient play a significant role in injury risk profiles of highly trained youth athletes. The results of the current study show that athletes maturing at a younger age are at significantly greater risk of injury, more than two-fold, compared to their later maturing counterparts. Taller athletes were also found to be significantly more at risk of injury.

There is limited and contrasting evidence on the relationship between maturity and injury in youth sports [27–29]. In this study, SA maturity (Fels method) showed that early maturing athletes had twice the risk of injury over a season compared to late maturing athletes. This finding is consistent with previous study [6], that described that early maturing athletes are significantly more at risk of injury than late or normally maturing athletes. A possible explanation could be that youth players with higher engagement and performance advantages are often associated with early maturation, usually transient during adolescence, and maybe reversed in early adulthood.

However, our study results were inconsistent with other study [28] on youth athletes, in which late maturing athletes have a higher injury rate compared to their earlier maturing counterparts. A plausible explanation could be that Fourchet et al. [28], examined anthropometric data collected from a track and field cohort for their findings, while our study resulted from maturity status derived from bone age.

In the present study, no significant association was observed between APHV and injury risk (HR 0.90, 95% CI 0.74–1.11, P = 0.329), which is inconsistent with recent data on youth alpine ski racing [30] and other studies on talented Dutch and English youth soccer players [6,31] which show a heightened period of risk around the time of peak height velocity. An explanation of these discrepancies could be that our study cohort was not large enough, as the APHV method appears to be useful in youth talent selection and injury prevention programs because it can be easily applied in a large cohort of young athletes [32].

PMH and %PMH at a given age are minimally invasive, feasibly practical indicators of somatic maturation [15,33], especially if mature height can be assessed without an estimate of SA [24]. In this study, the PMH and %PMH revealed that both indicators were associated with injury risk (HR 1.05, 95% CI 1.01–1.08, P = 0.006), and HR 1.03, 95% CI 1.00–1.06, P = 0.026), respectively. When compared to participants in the 1st quartile for PMH (<176), athletes in the 4th quartile (≥184 cm) had two and a half times greater risk of injury (HR 2.41, 95% CI 1.42–4.08, P = 0.001). The present results are partly in line with previous studies on other sports. Johnson et al. [6], showed that gains in height in youth footballers over a season were associated with an increased number of injuries. The study of Kemper et al. [34], on elite youth soccer players with growth rates of at least 0.6 cm/month showed a higher risk for injury. In a different study on soccer athletes, it was found that the tallest boys had the highest incidence of injury [35]. However, these findings and those of the present study are not in line with a study on youth football players [36], in which injured and non-injured players did not differ in percentage of mature height. An explanation could be that the definition of reportable injury in the methods of the study, which considered only time loss injuries, did not capture the full spectrum of injuries and therefore overlooked other injuries with insidious onset e.g. growth conditions.

The results of this study have some important practical implications. Malina et al. [2], advocate the documentation of anthropometric characteristics, biological maturity, and physical fitness parameters as crucial aids in the prevention of injury. Noninvasive methods for estimating maturity status may allow youth programs to match players using maturity status rather than CA, and thus equalize competition to some extent. An unequal competition is regarded as an impediment to personal development [37]. Furthermore, it has been suggested that there is an overwhelming bias in sport favoring taller athletes [38], and data on Olympic medal winners show that many running and jumping events are seriously biased in favor of the very tall [39].

When examining the classification resulting from SA of late (4%), normal (33%), early (41%), and skeletally mature athletes (22%), the under-representation of late and preponderance of early maturing athletes in this cohort is consistent with observations for male youth athletes in several sports including soccer and alpine ski racing [17,27,30]. However, these results and those of the present study are not in line with the study of Johnson et al. [6], on schoolboy footballers, in which two thirds of their players fall within the normal maturity category. Moreover, Le Gall et al. [14], classify only 12.0% as late maturers, 63.5% as normal maturers, and 24.5% as early maturers. These discrepancies are believed to be due to differences in selection policies and talent identification policies (physical, technical, and tactical skills) of varying elite development centers. Several studies point out that athletes who are more advanced in their biological maturity perform better than their later maturing peers and have a better chance of being selected [40–42]. Youth sport is highly selective, with a maturity-associated selection/exclusion process [33].

Implications and concepts for prevention

The findings in this study have several implications for youth athletes. First, our data suggests that adolescent athletes might be identified and selected with a preference for youths with advanced maturity. Such selection strategies which favor early maturers entail significant risks of injury. Accordingly, those involved in the selection and development of young athletes should be cognizant of temporary changes in motor control that may occur during these periods [43], consider maturity status, develop appropriate training programs to optimize training adaptation, design injury prevention plans to minimize activity related injury risk, and mitigate long term youth injury consequences.

Limitations of the current study should be noted. First, biological maturation methods have inherent limitations when applied to youth athletes and need to be applied with caution. Although SA is a gold standard indicator of maturation, it has major limitations in expense and minimal radiation and lack of knowledgeable staff for assessment protocols and the interpretation of results [44].

It must also be remembered that, except for accidents, a sports injury can rarely be ascribed to a single factor, but rather to an association of causes or circumstances and the interaction among a web of determinants [45,46].

CONCLUSIONS

The findings of the present study showed that maturity status plus PMH and %PMH are associated with injury in individual and racquet sports. As biological maturation varies individually in rate and timing, and mismatches in maturity may create competitive inequality and increase injury incidence, it is suggested that biological maturity should be considered during training to help prevent injury. Given the peculiarity of youth athletes it is important to optimize the planning of training activities to further improve the understanding of the link between training, growth, and injury.

Figure legends

<<<**Figure 1.** Flowchart describing the inclusion and flow of participants throughout the study >>>

<<<**Figure 2.** Kaplan-Meier survival analysis of injuries in relation to different skeletal age (SA) maturity status >>>

REFERENCES

1 Iuliano-Burns S, Mirwald RL, Bailey DA. Timing and magnitude of peak height velocity and peak tissue velocities for early, average, and late maturing boys and girls. *Am J Hum Biol* 2001;**13**:1–8. doi:10.1002/1520-6300(200101/02)13:1<1::AID-AJHB1000>3.0.CO;2-S

2 Malina RM, Cumming SP, Morano PJ, *et al.* Maturity status of youth football players: A noninvasive estimate. *Med Sci Sports Exerc* 2005;**37**:1044–52. doi:10.1249/01.mss.0000171622.45134.cb

3 Meeuwisse W. Assessing Causation in Sport Injury: A Multifactorial Model. *Clin J Sport Med* 1994;**4**:166–70. doi:10.1097/00042752-199407000-00004

4 Krivickas LS, Feinberg JH. Lower extremity injuries in college athletes: Relation between ligamentous laxity and lower extremity muscle tightness. *Arch Phys Med Rehabil* 1996;**77**:1139–43. doi:10.1016/S0003-9993(96)90137-9

5 Aicardi G, Vignolo M, Milani S, *et al.* Assessment of skeletal maturity of the hand-wrist and knee: A comparison among methods. *Am J Hum Biol* 2000;**12**:610–5. doi:10.1002/1520-6300(200009/10)12:5<610::AID-AJHB5>3.0.CO;2-D

6 Johnson A, Doherty PJ, Freemont A. Investigation of growth, development, and factors associated with injury in elite schoolboy footballers: prospective study. *Bmj* 2009;**338**:b490–b490. doi:10.1136/bmj.b490

7 Peterson HA. *Epiphyseal growth plate fractures*. 2007. doi:10.1007/978-3-540-33802-4

8 Bailey DA, Wedge JH, McCulloch RG, *et al.* Epidemiology of fractures of the distal end of the radius in children as associated with growth. *J Bone Jt SurgAm* 1989;**71**:1225–31.http://www.ncbi.nlm.nih.gov/pubmed/2777851

9 Lloyd RS, Oliver JL, Faigenbaum AD, *et al.* Chronological Age vs. Biological Maturation. *J Strength Cond Res* 2014;**28**:1454–64. doi:10.1519/JSC.0000000000000391

10 Deehan DJ, Bell K, McCaskie AW. Adolescent musculoskeletal injuries in a football academy. *J Bone Jt Surg - Br Vol* 2007;**89–B**:5–8. doi:10.1302/0301-620X.89B1.18427

11 Read P, Oliver JL, De Ste Croix MBA, *et al.* Injury Risk Factors in Male Youth Soccer Players. *Strength Cond J* 2015;**37**:1–7. doi:10.1519/SSC.0000000000000171

12 Huey K, Robinson MM, Wiesinger H-P, *et al.* Imbalances in the Development of Muscle and Tendon as Risk Factor for Tendinopathies in Youth Athletes: A Review of Current Evidence and Concepts of Prevention. 2017;**8**:1–18. doi:10.3389/fphys.2017.00987

13 Cumming SP, Brown DJ, Mitchell S, *et al.* Premier League academy soccer players' experiences of competing in a tournament bio-banded for biological maturation. J. Sports Sci. 2017;:1–9. doi:10.1080/02640414.2017.1340656

14 Le Gall F, Carling C, Reilly T. Biological maturity and injury in elite youth football. *Scand J Med Sci Sport* 2007;**17**:564–72. doi:10.1111/j.1600-0838.2006.00594.x

15 Beunen GP, Rogol AD, Malina RM. Indicators of biological maturation and secular changes in biological maturation. Food Nutr. Bull. 2006;**27**. doi:10.1177/156482650903000307

16 Ardern CL, Ekås G, Grindem H, *et al.* 2018 International Olympic Committee consensus statement on prevention, diagnosis and management of paediatric anterior cruciate

ligament (ACL) injuries. *Knee Surgery, Sport Traumatol Arthrosc* 2018;**0**:1–17. doi:10.1007/s00167-018-4865-y

17 Malina RM. Early sport specialization: Roots, effectiveness, risks. *Curr Sports Med Rep* 2010;**9**:364–71. doi:10.1249/JSR.0b013e3181fe3166

18 Leppänen M, Lapinleimu H, Lehtonen L, *et al.* Growth of extremely preterm infants born in 2001-2010. *Acta Paediatr Int J Paediatr* 2013;**102**:206–8. doi:10.1111/apa.12061

19 Steffen K. More data needed on injury risk among young elite athletes. *Br J Sports Med* 2010;**44**:485–9.http://search.ebscohost.com/login.aspx?direct=true&db=sph&AN=51172712&site=ehost-live

20 Rejeb A, Johnson A, Vaeyens R, *et al.* Compelling overuse injury incidence in youth multisport athletes. *Eur J Sport Sci* 2017;**17**:495–502. doi:10.1080/17461391.2016.1275820

21 Malisoux L, Frisch A, Urhausen A, *et al.* Injury incidence in a sports school during a 3-year follow-up. *Knee Surgery, Sport Traumatol Arthrosc* 2013;**21**:2895–900. doi:10.1007/s00167-012-2185-1

22 Fuller CW, Ekstrand J, Junge A, *et al.* Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Scand. J. Med. Sci. Sport. 2006;**16**:83–92. doi:10.1111/j.1600-0838.2006.00528.x

23 Meeuwisse W, H MD P, Tyreman H, *et al.* A Dynamic Model of Etiology in Sport Injury: The Recursive Nature of Risk and Causation. *Clin J Sport Med* 2007;**17**:215–9. doi:10.1097/JSM.0b013e3180592a48

24 Khamis HJ, Roche AF. Predicting adult stature without using skeletal age: the Khamis-

Roche method. Pediatrics. 1994;**94**:504–7. doi:10.1016/S0740-624X(98)90020-X

25 Silventoinen K, Pke M, Tynelius P. Muscle Strength and Body Size and Later Cerebrovascular and Coronary Heart Disease Maturity Status and Injury Risk in Youth Soccer Players. *Sport Med* 2010;**20**:131–5. doi:10.1136/bmj.b490.Objective

26 Timpka T, Alonso J-M, Jacobsson J, *et al.* Injury and illness definitions and data collection procedures for use in epidemiological studies in Athletics (track and field): Consensus statement. *Br J Sports Med* 2014;**48**:483–90. doi:10.1136/bjsports-2013-093241

27 Materne O, Farooq A, Johnson A, *et al.* Relationship between injuries and somatic maturation in highly trained youth soccer players. *Int Res Sci Soccer II* 2016;:182–92.https://books.google.com/books?hl=en&lr=&id=w8DMCgAAQBAJ&oi=fnd&pg=PA182&dq=Relationship+between+injuries+and+somatic+maturation+in+highly+trained+youth+soccer+players&ots=6D7Xy7rLzj&sig=ywUDNrV1u4pMrJlBN3wERj1u93M%5Cnhttp://s3.amazonaws.com/academia.edu.

28 Fourchet F, Horobeanu C, Loepelt H, *et al.* Foot, Ankle, and Lower Leg Injuries in Young Male Track and Field Athletes. *Int J Athl Ther Train* 2011;**16**:19–23 5p. doi:10.1123/ijatt.16.3.19

29 Swain M, Kamper SJ, Maher CG, *et al.* Relationship between growth, maturation and musculoskeletal conditions in adolescents: a systematic review. *Br J Sports Med* 2018;:bjsports-2017-098418. doi:10.1136/bjsports-2017-098418

30 Müller L, Hildebrandt C, Müller E, *et al.* Long-Term athletic development in youth alpine ski racing: The effect of physical fitness, ski racing technique, anthropometrics and biological maturity status on injuries. *Front Physiol* 2017;**8**. doi:10.3389/fphys.2017.00656

31 Vanderlei FM, Vanderlei LCM, Bastos FN, *et al.* Characteristics and associated factors with sports injuries among children and adolescents. *Brazilian J Phys Ther* 2014;**18**:530–7. doi:10.1590/bjpt-rbf.2014.0059

32 Müller L. Müller EHCKK& RC. Die Erhebung des biologischen Entwicklungsstandes fur die Talentselektion - welche Methode eignet sich? [The assessment of biological maturation for talent selection - which method can be used?]. *Sport Sport* 2015;**29**:56–63.

33 Bergeron MF, Mountjoy M, Armstrong N, *et al.* International Olympic Committee consensus statement on youth athletic development. *Br J Sports Med* 2015;**49**:843–51. doi:10.1136/bjsports-2015-094962

34 Kemper GLJ, Van Der Sluis A, Brink MS, *et al.* Anthropometric Injury Risk Factors in Elite-standard Youth Soccer. *Int J Sports Med* 2015;**36**:1112–7. doi:10.1055/s-0035-1555778

35 Backous DD, Friedl KE, Smith NJ, *et al.* Soccer Injuries and Their Relation to Physical Maturity. *Am J Dis Child* 1988;**142**:839–42. doi:10.1001/archpedi.1988.02150080045019

36 Malina RM, Morano PJ, Barron M, *et al.* Incidence and player risk factors for injury in youth football. *Clin J Sport Med* 2006;**16**:214–22. doi:10.1097/00042752-200605000-00005

37 Musch J, Grondin S. Unequal Competition as an Impediment to Personal Development: A Review of the Relative Age Effect in Sport. *Dev Rev* 2001;**21**:147–67. doi:10.1006/drev.2000.0516

38 Baxter-Jones ADG. Growth and Development of Young Athletes: Should Competition Levels be Age Related? *Sport Med* 1995;**20**:59–64. doi:10.2165/00007256-199520020-00001

39 Khosla T. Unfairness of certain events in the Olympic games. *Br Med J* 1968;**4**:111–3. doi:10.1136/bmj.4.5623.111

40 Beunen GP, Malina RM, Van't Hof MA, *et al. Adolescent Growth and Motor Performance*. 1988.

41 Philippaerts RM, Vaeyens R, Janssens M, *et al.* The relationship between peak height velocity and physical performance in youth soccer players. *J Sports Sci* 2006;**24**:221–30. doi:10.1080/02640410500189371

42 Malina RM, Bouchard C, Bar-Or O. Growth, maturation, and physical activity. *Growth, Matur Phys Perform* 2004;:1–17.

43 Mueller L, Hildebrandt C, Mueller E, *et al.* Injuries and illnesses in a cohort of elite youth alpine ski racers and the influence of biological maturity and relative age: a two-season prospective study. *Open Access J Sport Med* 2017;**Volume 8**:113–22. doi:10.2147/OAJSM.S133811

44 Malina RM, Rogol AD, Cumming SP, *et al.* Biological maturation of youth athletes: assessment and implications. *Br J Sports Med* 2015;**49**:852–9. doi:10.1136/bjsports-2015-094623

45 Theisen D, Malisoux L, Seil R, *et al.* : Injuries in Youth Sports: Epidemiology, Risk Factors and Prevention. *Dtsch Z Sportmed* 2014;**65**:S248-252.http://www.zeitschrift-sportmedizin.de/artikel-online/archiv-2014/heft-9/injuries-in-youth-sports-epidemiology-risk-factors-and-prevention/

46 Bittencourt NFN, Meeuwisse WH, Mendonça LD, *et al.* Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition—narrative review and new concept. *Br J Sports Med* 2016;**50**:1309–14.

doi:10.1136/bjsports-2015-095850

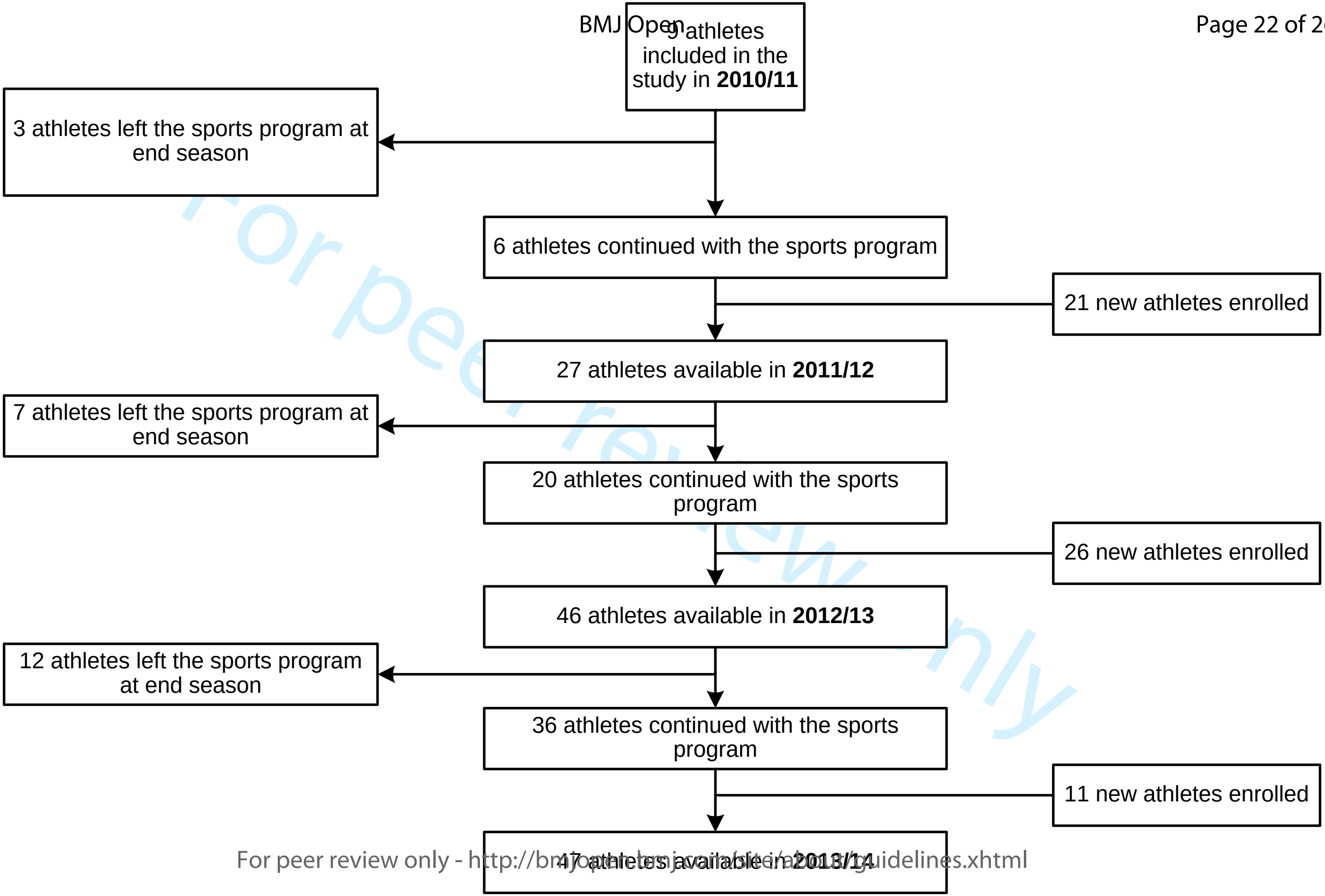
Contributors AR and EW designed and developed the research question. AR, AJ and EW were involved in study design. AF supervised the data collection. AF analysed and interpreted the data. AR wrote the manuscript. All authors have contributed to and edited the manuscript and have approved the final manuscript.

Funding This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Ethics approval The study received ethical approval by the Anti-doping Lab Qatar

Data sharing statement No additional data are available


9 athletes included in the study in **2010/11**
3 athletes left the sports program at end season
6 athletes continued with the sports program
21 new athletes enrolled
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7 athletes left the sports program at end season
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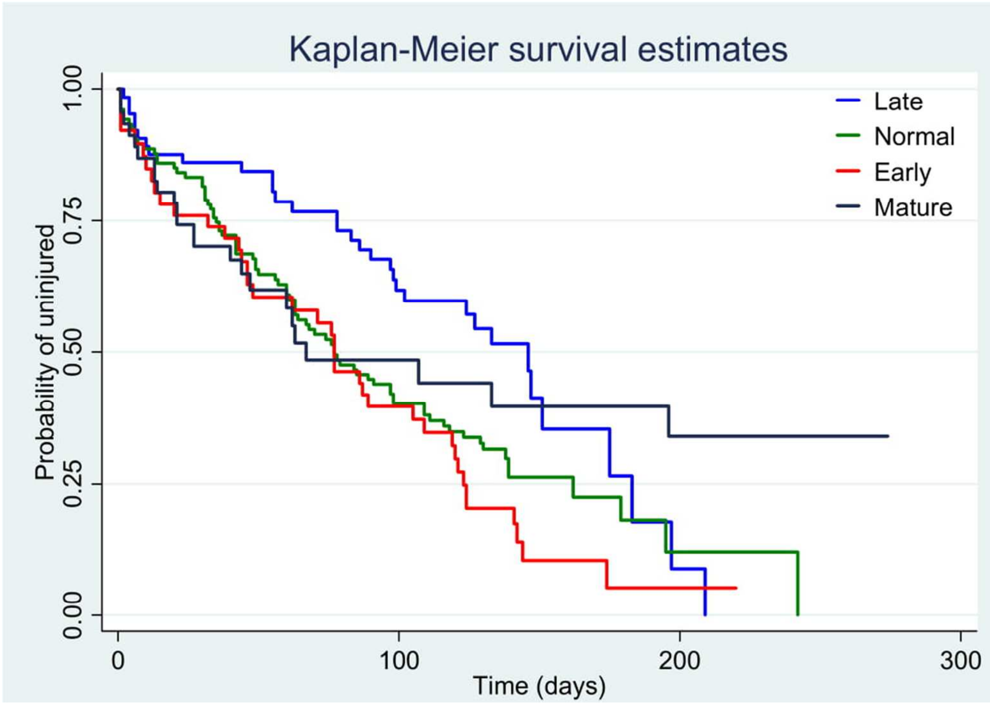
11 new athletes enrolled
47 athletes available in **2013/14**



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STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	**Item #**	**Recommendation**	**Reported on page #**
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Page 1 and Page 2.
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Pages 2 and 3.
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Pages 4.
Objectives	3	**State specific objectives, including any prespecified hypotheses**	Pages 4 and 5.
Methods			
Study design	4	Present key elements of study design early in the paper	Page 5, line of methods 82
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 5.
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Pages 5 and 6. Figure 1.
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	On pages 6, 7 and 8. Definition and data collection of outcome variables were given.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	On Pages 7 and 8.
Bias	9	Describe any efforts to address potential sources of bias	On Page 8.
Study size	10	Explain how the study size was arrived at	Every available athlete was included in our study.
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 5.

Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Pages 8.
		(*b*) Describe any methods used to examine subgroups and interactions	Pages 5 and 6
		(*c*) Explain how missing data were addressed	Not applicable
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	Not applicable
		(*e*) Describe any sensitivity analyses	Not applicable
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	All participants eligible completed the study. Page 7
		(b) Give reasons for non-participation at each stage	Not applicable
		(c) Consider use of a flow diagram	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Table 1
		(b) Indicate number of participants with missing data for each variable of interest	(Not applicable)
Outcome data	15*	Report numbers of outcome events or summary measures	Page 8 and page 9
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Table 1.
		(*b*) Report category boundaries when continuous variables were categorized	Not applicable
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Figure 2. different maturity level compared.
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 10.
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 13.
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 13.
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 13.
Other information			

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Not applicable

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Sports Injuries Aligned to Predicted Mature Height in Highly Trained Middle-Eastern Youth Athletes: A Cohort study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-023284.R1
Article Type:	Research
Date Submitted by the Author:	25-Sep-2018
Complete List of Authors:	Rejeb, Abdallah; Aspetar Qatar Orthopaedic and Sports Medicine Hospital, Aspire Academy Sports Medicine Center; Universiteit Gent Faculteit Geneeskunde en Gezondheidswetenschappen, Rehabilitation Sciences and Physiotherapie Johnson, Amanda; Aspetar Qatar Orthopaedic and Sports Medicine Hospital, Aspire Academy Sports Medicine Center Farooq, Abdulaziz; Aspetar, Orthopaedic and Sports Medicine Department, Athlete Health and Performance Research Verrelest, Ruth ; Universiteit Gent Faculteit Geneeskunde en Gezondheidswetenschappen, Rehabilitation Sciences and Physiotherapie Pullinger, Samuel; ASPIRE Academy for Sports Excellence, Sports Sciences Vaeyens, Roel ; Universiteit Gent Faculteit Geneeskunde en Gezondheidswetenschappen, Department of movement and Sports Sciences Witvrouw, Erik; Universiteit Gent Faculteit Geneeskunde en Gezondheidswetenschappen, Rehabilitation Sciences and Physiotherapy
Primary Subject Heading:	Sports and exercise medicine
Secondary Subject Heading:	Paediatrics
Keywords:	Youth, Biological maturation, Skeletal age, Anthropometrics, Sports injury, Mature height

Sports Injuries Aligned to Predicted Mature Height in Highly Trained Middle-Eastern Youth Athletes: A Cohort study

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Manuscript word count = 3201

ABSTRACT (296/300 words)

OBJECTIVES: To investigate the association of maturity status with injury incidence in Middle-Eastern youth athletes.

DESIGN: Prospective cohort study

SETTING: Four consecutive seasons (2010 to 2014), Aspire Academy, Qatar.

PARICIPANTS: Male athletes (age range: 11–18 y) representing four disciplines enrolled and grouped into two categories: individual sports and racquet sports.

OUTCOME MEASURES: Injury data collected over four seasons. Athletes' anthropometric characteristics assessed to calculate APHV. Predicted mature heights (PMHs) collected and categorized into four quartiles. Athletes had wrist and hand radiographs for assessment of skeletal age (SA). Early and late maturers with an SA of >1 y older or younger than their chronological age (CA).

RESULTS: For the sample (n = 67) across all groups, 43 (64%) athletes had one or more injuries: total of 212 injuries, 4.9 injuries per athlete across study. Survival analysis of maturity status using SA found early maturing athletes had two-fold greater injury risk compared to late maturers ([HR]; 2.04, 95% CI 1.15–3.61, P = 0.015). PMH associated with injury risk (HR 1.05, 95% CI 1.01–1.08, P = 0.006).

Athletes in 4th quartile (≥ 184 cm) had up to 2-fold injury risk (HR 2.41, 95% CI 1.42–4.08, P = 0.001). Racquet and individual sports involved similar injury risk (HR 1.14, 95% CI 0.86–1.52, P = 0.37).

CONCLUSION: SA early maturity and PMH gradient were significant predictors of injury in youths.

STRENGTHS AND LIMITATIONS OF THE STUDY

- First longitudinal study to assess anthropometric characteristics and biological maturity status as injury risk factors in Middle-Eastern athletes.
- Participants were highly trained adolescent athletes.
- Measurement of maturity and growth were at moderate-to-high risk of bias**.**
- SA has major limitations in expense and minimal radiation and lack of knowledgeable staff for assessment and interpretation of results.

INTRODUCTION

The range of somatic and biological maturity in individuals of the same chronological age (CA) is large [1]. Such observations are derived from correlational and multivariate studies that compare young individuals of the same age who are at both extremes of the maturity range [2]. Therefore, the assessment of maturity is an important consideration when dealing with adolescent athletes on a longitudinal basis. Further, understanding the cause of disease and injury is vital in predicting and preventing injury [3].

In young athletes, the demands of their chosen sport are superimposed on normal growth and maturation. A literature review revealed that there is a greater susceptibility to injury during certain periods of growth [4–6]. Indeed, the association between an increased prevalence of injuries and the adolescent growth spurt has long been recognized [7–9]. A recent study analysis [10] on adolescent soccer players revealed greater risk of injury with players within age at peak height velocity (APHV) in comparison with the players before and after APHV. Mismatched rapid growth in the long bones relative to muscular lengthening may disrupt structure, neuromuscular function, and physical performance [11].

Deehan et al. [12], state that an increased participation in sports predisposes the immature skeleton to injury. Furthermore, participation in high intensity sport entails an inherent risk of sports-related injuries, and this is heightened at various stages of growth and maturation [13]. Maturation induces profound changes in the skeletal, neuromuscular, and tendinous systems of young athletes [14] and mismatches in biological maturity may create competitive inequality and increase the risk of injury [15]. Le Gall et al. [16], further point out that injury rates generally increase with increasing CA. However, CA is a poor indicator of biological maturity [17]; moreover, Ardern et al. [18], report that chronological age alone is an unreliable indicator of skeletal maturity. Skeletal age (SA) is generally accepted as the most accurate method of assessing biological maturity [6,19], by identifying critical periods of development; it also offers a rational method for monitored age-specific training. Before initiating any program for mitigating sports injuries, the magnitude of the problem must be identified and the extent of the injury defined in terms of incidence and severity [20].

A number of studies have been conducted involving injuries in adolescent footballers; conversely, few studies have focused on injuries in non-footballer adolescent athletes in high performance sporting environments [21]. Studies of anthropometric characteristics and biological maturity status as injury risk factors in Middle-Eastern youths are also limited, highlighting the need for more research in this area. Therefore, the purpose of the present study was to investigate injury incidence according to biological maturity using two outcome measures (SA and PHV) in highly trained youth athletes based at a Middle Eastern Sports Academy.

METHODS

Sixty-seven highly trained adolescent athletes (age range 11–18 y) representing athletics and racquet sports (table tennis and squash) from a Middle Eastern sports school were included in this four-year study. A prospective, longitudinal cohort design was used and included separate observation periods over four consecutive seasons (2010–2011, 2011–2012, 2012–2013, and 2013–2014), i.e., school years, which lasted from the beginning of September until the end of June (~40 weeks). Participant maturity assessments included both anthropometric measurements, collected three times a season, and SA assessments using Fels method completed once, at the start of every season. Medical screening was performed at the beginning of each season to determine health and injury status. All selected athletes had clearance from a physician to participate in their respective sport. Written informed consent was sought and obtained from parents and assent from all participants. The study was part of a general sports science provision to the sports academy, and all procedures were reviewed and granted by the Institutional Review Board (IRB) for Human Subjects and conformed to the recommendations of the Declaration of Helsinki.

Participants

Figure 1 shows the flow of participants in the study over consecutive seasons. A total of four sporting disciplines were analysed, grouped into two categories: athletics and fencing and racquet sports (squash and table tennis). This classification was based on specific sport characteristics and injury risk [22,23]. Inclusion criteria were as follows: (1) the athlete had to be enrolled in the sports school during at least one full school year; (2) athletes with injuries in previous seasons were not excluded from this study, but injuries present at the beginning of the observation period were not included in statistical analyses; and (3) injuries that were not sustained in the context of the sports program (e.g. recreational activities) or data related to sickness or other general medical conditions were not used for further analysis.

<<<Insert Figure 1 here>>>

Injury definition and data collection

An Injury was defined as any physical complaint, which occurred during sports training, strength and conditioning training or during competition. Injuries were divided into time-loss (TL) injuries and no time-loss (NTL) injuries. A clinical examination and/or treatment of an athlete which did not result in a full training session or competition being missed was described as a complaint with NTL injury. A clinical examination and/or treatment of an athlete resulting in a training session or competition being missed the following day(s) was labelled as a TL injury [23]. A traumatic injury was defined as any injury resulting from a specific and identifiable mechanism, including contact and non-contact circumstances with acute onset. Overuse injuries were defined as injuries resulting from insidious onset without a recognizable mechanism. Injury severity was defined, based on days of absence from usual sport participation, as slight (1 d or less), minimal (2–3 d), mild (4–7 d), moderately serious (8–28 d), serious (>28 d up to 6 months) or long-term (>6 months) in accordance with [24].

All injuries were collected by a physical therapist (AR) with experience of working within youth sport. Data from medical records were used to document all sports related injuries during the study. Each sporting discipline had a dedicated full-time physiotherapist and a full-time employed medical doctor at the sports academy. The medical record used an injury reporting system based upon the football injury reporting system [25] and the Sport Medicine Diagnostic Coding System [26]. Information was gathered concerning all injuries related to sports activity, including several related variables (e.g. type, location, affected structure, mechanism [acute vs. overuse], time loss, severity, and date of injury).

Somatic maturation and anthropometric measurements

Anthropometric measurements were initially carried out on all participants on a three monthly basis along with an estimation of the age at peak height velocity (APHV) as a relative indicator of somatic maturity and representing the time of maximum growth in stature during adolescence using Mirwald method [27] for the prediction of growth [1]. APHV was calculated from the first measurement recorded. To ensure that the outcome measures remained consistent and reliable, every effort was made to ensure that measurements were taken at approximately the same time of the season. Measurements were collected by qualified practitioners from the

International Society for the Advancement of Kinanthropometry (ISAK) and included stretch stature (± 0.1 cm Holtain Limited, Crosswell, UK).

The predicted mature height (PMH) of all participants were collected and categorized into four PMH quartiles (Q1–Q4: Q1 < 176 cm; 176 cm ≤ Q2 < 180 cm; 180 cm ≤ Q3 < 184 cm; Q4 ≥ 184 cm). The athletes were then divided into three maturity groups (late, normal, or early maturing) based on the mean ± 1.0 year of the APHV of the total sample (late, APHV > mean + 1.0 y; normal, APHV within mean ± 1.0 y; early, APHV < mean – 1.0 y). Years from peak height velocity (maturity offset value: CA – maturity offset) was calculated by subtracting the CA at the date of injury from the age at estimated peak height velocity.

Skeletal maturation assessment

Each year athletes were required to have a radiograph of the left wrist and hand, a convenient area to examine, and a more accurate method for the assessment of SA [11], using the Fels method [6,28] which has an advantage over other methods [29]. Maturity status, defined by the difference between CA and SA was calculated and classified into four categories: late, normal, early, and mature athletes. Late referred to an SA that was younger than CA by more than 1.0 y, athletes with a normal pattern of maturity had an SA that was within 1.0 y of CA, early referred to an SA that was older than CA by more than 1.0 y, and the closure of growth plate determine skeletally mature athletes.

Statistical Analysis

Data were analysed using statistical software (Stata Corporation, College Station, Texas). Descriptive statistics were presented as frequencies and proportions (%), and incidence rates were expressed as the number of injuries/number of registered athletes. To examine the role of growth status and maturity with the onset of injuries, a univariate Cox regression survival analysis was performed after accounting for repeated visits of athletes over the four seasons.

Hazard ratios (HR) with 95% confidence intervals (CIs) were reported for each factor. Kaplan-Meier curves were plotted for SA groups and time to injury over a season. Where appropriate, 95% CIs are presented. The alpha level of significance was set at 5%.

Patient and public involvement statement

Patients and public were not involved in the analysis of this study.

RESULTS

Throughout the four-year seasons study period, 67 athletes were enrolled representing 151 athletic seasons. Table 1 presents the anthropometric characteristics of participants and their maturity status. From these participants, 43 (64%) reported one or more injuries adding up to 212 injuries in total., The injury rate observed per registered athlete amounted to 4.9 injuries over the course of four seasons.

Table 1. Anthropometric characteristics (mean ± SD) of participants according to maturity status

	Late	Normal	Early
	(n = 4, 6.0%)	(n = 59, 88.1%)	(n = 4, 6.0%)
CA (years)	13.3 ± 1.1	12.3 ± 1.0	12.1 ± 0.5
Years from PHV	-2.4 ± 1.2	-1.6 ± 1.1	-0.1 ± 0.9
APHV (years)	15.8 ± 1.5	13.9 ± 0.5	12.2 ± 0.9
PMH (cm)	181.6 ± 17.1	179.4 ± 4.9	188.4 ± 3.5
% PMH (%)	85.0 ± 3.0	85.0 ± 4.0	90.0 ± 4.0
SA (years)	11.8 ± 0.5	12.8 ± 1.5	12.7 ± 1.8

CA: chronological age; APHV: age at peak height velocity; PMH: predicted mature height; SA: skeletal age; SD: standard deviation

Skeletal age: maturity status distribution and injury risk

Among all participants (n = 67), 4% were classified as late maturers, 33% as normal, 41% as early and 22% as skeletally mature. The overall injury free survival analysis of maturity status using SA assessment indicated that early maturing athletes had a two-fold higher risk of injury over a season compared to late maturing athletes (HR 2.04, 95% CI 1.15–3.61, P = 0.015),

(Figure 2). There was a trend that early maturing athletes had a greater risk of injury over a season compared to normal athletes (HR 1.62, 95% CI 0.99–2.65, P = 0.053), but this was only marginally significant. However, injury risk among late and fully mature athletes did not differ from normal maturers.

<<<<Insert Figure 2 Here >>>>

Somatic maturation and anthropometric measurements: distribution and injury risk

Using anthropometric measurements, among all participants (n = 67), 6.0% were classified as late maturing, 85.8% as normal, and 6.0% as early. Classification of participant maturity status (late, normal, and early) according to age at PHV (APHV) was not significantly associated with overall injury incidence in this cohort of highly trained Middle-Eastern youth athletes. Older PHVs were marginally associated with higher injury risk, but this was not statistically significant (HR 1.11, 95% CI 0.99–1.23, P = 0.067).

Both PMH (cm), and %PMH were found to be associated with injury risk (HR 1.05, 95% CI 1.01–1.08, P = 0.006, and HR 1.03, 95% CI 1.00–1.06, P = 0.026), respectively. When compared to participants in the 1st quartile for PMH (<176), athletes in the 4th quartile (≥184 cm) had a two and half times greater risk of injury (HR 2.41, 95% CI 1.42–4.08, P = 0.001) over a season.

No significant differences were observed in the injury risk between racquet sports (n = 30) and individual sports athletes (n = 37; HR 1.14, 95% CI, 0.86–1.52, P = 0.37).

DISCUSSION

The present investigation was carried out to examine injury incidence according to maturity status. Biological maturity status and height gradient play a significant role in injury risk profiles of highly trained youth athletes. The results of the current study show that athletes maturing at a younger age are at significantly greater risk of injury, more than two-fold, compared to their later maturing counterparts. Taller athletes were also found to be significantly more at risk of injury.

There is limited and contrasting evidence on the relationship between maturity and injury in youth sports [10,30,31]. In this study, SA maturity (Fels method) showed that early maturing athletes had twice the risk of injury over a season compared to late maturing athletes. This finding is consistent with previous study [6], that described that early maturing athletes are significantly more at risk of injury than late or normally maturing athletes. A possible explanation could be that youth players with higher engagement and performance advantages are often associated with early maturation, usually transient during adolescence, and maybe reversed in early adulthood [16]

However, our study results were inconsistent with other study [30] on youth athletes, in which late maturing athletes have a higher injury rate compared to their earlier maturing counterparts. A plausible explanation could be that Fourchet et al. [30], examined anthropometric data collected from a track and field cohort for their findings, while our study resulted from maturity status derived from bone age but with no substantial association from APHV.

In the present study, no significant association was observed between APHV and injury risk (HR 0.90, 95% CI 0.74–1.11, P = 0.329), which is inconsistent with recent data on youth alpine ski racing [32] and other studies on talented Dutch and English youth soccer players [6,33] which show a heightened period of risk around the time of peak height velocity. An explanation of these discrepancies could be that our study cohort was not large enough, as the APHV method appears to be useful in youth talent selection and injury prevention programs because it can be easily applied in a large cohort of young athletes [34].

PMH and %PMH at a given age are minimally invasive, feasibly practical indicators of somatic maturation [17,35], especially if mature height can be assessed without an estimate of SA [28].

In this study, the PMH and %PMH revealed that both indicators were associated with injury risk (HR 1.05, 95% CI 1.01–1.08, P = 0.006), and HR 1.03, 95% CI 1.00–1.06, P = 0.026), respectively. When compared to participants in the 1st quartile for PMH (<176), athletes in the 4th quartile (≥184 cm) had two and a half times greater risk of injury (HR 2.41, 95% CI 1.42–4.08, P = 0.001). The present results are partly in line with previous studies on other sports. Johnson et al. [6], showed that gains in height in youth footballers over a season were associated with an increased number of injuries. The study of Kemper et al. [36], on elite youth soccer players with growth rates of at least 0.6 cm/month showed a higher risk for injury. In a different study on soccer athletes, it was found that the tallest boys had the highest incidence of injury [37]. However, these findings and those of the present study are not in line with a study on youth football players [38], in which injured and non-injured players did not differ in percentage of mature height. An explanation could be that the definition of reportable injury in the methods of the study, which considered only time loss injuries, did not capture the full spectrum of injuries and therefore overlooked other injuries with insidious onset e.g. growth conditions.

The results of this study have some important practical implications. Malina et al. [2], advocate the documentation of anthropometric characteristics, biological maturity, and physical fitness parameters as crucial aids in the prevention of injury. Noninvasive methods for estimating maturity status may allow youth programs to match players using maturity status rather than CA, and thus equalize competition to some extent. An unequal competition is regarded as an impediment to personal development [39]. Furthermore, it has been suggested that there is an overwhelming bias in sport favoring taller athletes [40], and data on Olympic medal winners show that many running and jumping events are seriously biased in favor of the very tall [41].

When examining the classification resulting from SA of late (4%), normal (33%), early (41%), and skeletally mature athletes (22%), the under-representation of late and preponderance of early maturing athletes in this cohort is consistent with observations for male youth athletes in several sports including soccer and alpine ski racing [10,19,32]. However, these results and those of the present study are not in line with the study of Johnson et al. [6], on schoolboy footballers, in which two thirds of their players fall within the normal maturity category. Moreover, Le Gall et al. [16], classify only 12.0% as late maturers, 63.5% as normal maturers, and 24.5% as early maturers. These discrepancies are believed to be due to differences in selection policies and talent identification policies (physical, technical, and tactical skills) of varying elite development centers. Several studies point out that athletes who are more advanced in their biological maturity perform better than their later maturing peers and have a better chance of being selected [42–44]. Youth sport is highly selective, with a maturity-associated selection/exclusion process [35].

Implications and concepts for prevention

The findings in this study have several implications for youth athletes. First, our data suggests that adolescent athletes might be identified and selected with a preference for youths with advanced maturity. Such selection strategies which favor early maturers entail significant risks of injury. Accordingly, those involved in the selection and development of young athletes should be cognizant of temporary changes in motor control that may occur during these periods [45], consider maturity status, develop appropriate training programs to optimize training adaptation, design injury prevention plans to minimize activity related injury risk, and mitigate long term youth injury consequences.

Limitations of the current study should be noted. First, biological maturation methods have inherent limitations when applied to youth athletes and need to be applied with caution. Although SA is a gold standard indicator of maturation, it has major limitations in expense and minimal radiation and lack of knowledgeable staff for assessment protocols and the interpretation of results [46]. Although our sample size is small, we have a follow-up over four seasons. Another limitation, we had no data on training or competition exposure, which reduces the comparability with other studies reporting injury incidence.

It must also be remembered that, except for accidents, a sports injury can rarely be ascribed to a single factor, but rather to an association of causes or circumstances and the interaction among a web of determinants [47,48].

CONCLUSIONS

The findings of the present study showed that maturity status plus PMH and %PMH are associated with injury in individual and racquet sports but no association has been established between APHV and injury. As SA varies individually in rate and timing, and mismatches in maturity may create competitive inequality and increase injury incidence, it is suggested that biological maturity should be considered during training to help prevent injury. Given the peculiarity of youth athletes it is important to optimize the planning of training activities to further improve the understanding of the link between training, growth, and injury.

Figure legends

<<<Figure 1. Flowchart describing the inclusion and flow of participants throughout the study >>>

<<<Figure 2. Kaplan-Meier survival analysis of injuries in relation to different skeletal age (SA) maturity status >>>

REFERENCES

1 Iuliano-Burns S, Mirwald RL, Bailey DA. Timing and magnitude of peak height velocity and peak tissue velocities for early, average, and late maturing boys and girls. *Am J Hum Biol* 2001;**13**:1–8. doi:10.1002/1520-6300(200101/02)13:1<1::AID-AJHB1000>3.0.CO;2-S

2 Malina RM, Cumming SP, Morano PJ, *et al.* Maturity status of youth football players: A

noninvasive estimate. *Med Sci Sports Exerc* 2005;**37**:1044–52. doi:10.1249/01.mss.0000171622.45134.cb

3 Meeuwisse W. Assessing Causation in Sport Injury: A Multifactorial Model. *Clin J Sport Med* 1994;**4**:166–70. doi:10.1097/00042752-199407000-00004

4 Krivickas LS, Feinberg JH. Lower extremity injuries in college athletes: Relation between ligamentous laxity and lower extremity muscle tightness. *Arch Phys Med Rehabil* 1996;**77**:1139–43. doi:10.1016/S0003-9993(96)90137-9

5 Aicardi G, Vignolo M, Milani S, *et al.* Assessment of skeletal maturity of the hand-wrist and knee: A comparison among methods. *Am J Hum Biol* 2000;**12**:610–5. doi:10.1002/1520-6300(200009/10)12:5<610::AID-AJHB5>3.0.CO;2-D

6 Johnson A, Doherty PJ, Freemont A. Investigation of growth, development, and factors associated with injury in elite schoolboy footballers: prospective study. *Bmj* 2009;**338**:b490–b490. doi:10.1136/bmj.b490

7 Peterson HA. *Epiphyseal growth plate fractures*. 2007. doi:10.1007/978-3-540-33802-4

8 Bailey DA, Wedge JH, McCulloch RG, *et al.* Epidemiology of fractures of the distal end of the radius in children as associated with growth. *J Bone Jt SurgAm* 1989;**71**:1225–31.http://www.ncbi.nlm.nih.gov/pubmed/2777851

9 Leppänen M, Pasanen K, Clarsen B, *et al.* Overuse injuries are prevalent in children's competitive football: a prospective study using the OSTRC Overuse Injury Questionnaire. *Br J Sports Med* 2018;:bjsports-2018-099218. doi:10.1136/bjsports-2018-099218

10 Materne O, Farooq A, Johnson A, *et al.* Relationship between injuries and somatic maturation in highly trained youth soccer players. *Int Res Sci Soccer II* 2016;:182–92.https://books.google.com/books?hl=en&lr=&id=w8DMCgAAQBAJ&oi=fnd&pg=PA182

&dq=Relationship+between+injuries+and+somatic+maturation+in+highly+trained+youth+soccer+players&ots=6D7Xy7rLzj&sig=ywUDNrV1u4pMrJlBN3wERj1u93M%5Cnhttp://s3.amazonaws.com/academia.edu.

11 Lloyd RS, Oliver JL, Faigenbaum AD, *et al.* Chronological Age vs. Biological Maturation. *J Strength Cond Res* 2014;**28**:1454–64. doi:10.1519/JSC.0000000000000391

12 Deehan DJ, Bell K, McCaskie AW. Adolescent musculoskeletal injuries in a football academy. *J Bone Jt Surg - Br Vol* 2007;**89–B**:5–8. doi:10.1302/0301-620X.89B1.18427

13 Read P, Oliver JL, De Ste Croix MBA, *et al.* Injury Risk Factors in Male Youth Soccer Players. *Strength Cond J* 2015;**37**:1–7. doi:10.1519/SSC.0000000000000171

14 Huey K, Robinson MM, Wiesinger H-P, *et al.* Imbalances in the Development of Muscle and Tendon as Risk Factor for Tendinopathies in Youth Athletes: A Review of Current Evidence and Concepts of Prevention. 2017;**8**:1–18. doi:10.3389/fphys.2017.00987

15 Cumming SP, Brown DJ, Mitchell S, *et al.* Premier League academy soccer players' experiences of competing in a tournament bio-banded for biological maturation. J. Sports Sci. 2017;:1–9. doi:10.1080/02640414.2017.1340656

16 Le Gall F, Carling C, Reilly T. Biological maturity and injury in elite youth football. *Scand J Med Sci Sport* 2007;**17**:564–72. doi:10.1111/j.1600-0838.2006.00594.x

17 Beunen GP, Rogol AD, Malina RM. Indicators of biological maturation and secular changes in biological maturation. Food Nutr. Bull. 2006;**27**. doi:10.1177/156482650903000307

18 Ardern CL, Ekås G, Grindem H, *et al.* 2018 International Olympic Committee consensus statement on prevention, diagnosis and management of paediatric anterior cruciate ligament (ACL) injuries. *Knee Surgery, Sport Traumatol Arthrosc* 2018;**0**:1–17.

doi:10.1007/s00167-018-4865-y

19 Malina RM. Early sport specialization: Roots, effectiveness, risks. *Curr Sports Med Rep* 2010;**9**:364–71. doi:10.1249/JSR.0b013e3181fe3166

20 Leppänen M, Lapinleimu H, Lehtonen L, *et al.* Growth of extremely preterm infants born in 2001-2010. *Acta Paediatr Int J Paediatr* 2013;**102**:206–8. doi:10.1111/apa.12061

21 Steffen K. More data needed on injury risk among young elite athletes. *Br J Sports Med* 2010;**44**:485–9.http://search.ebscohost.com/login.aspx?direct=true&db=sph&AN=51172712&site=ehost-live

22 Rejeb A, Johnson A, Vaeyens R, *et al.* Compelling overuse injury incidence in youth multisport athletes. *Eur J Sport Sci* 2017;**17**:495–502. doi:10.1080/17461391.2016.1275820

23 Malisoux L, Frisch A, Urhausen A, *et al.* Injury incidence in a sports school during a 3-year follow-up. *Knee Surgery, Sport Traumatol Arthrosc* 2013;**21**:2895–900. doi:10.1007/s00167-012-2185-1

24 Timpka T, Alonso J-M, Jacobsson J, *et al.* Injury and illness definitions and data collection procedures for use in epidemiological studies in Athletics (track and field): Consensus statement. *Br J Sports Med* 2014;**48**:483–90. doi:10.1136/bjsports-2013-093241

25 Fuller CW, Ekstrand J, Junge A, *et al.* Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Scand. J. Med. Sci. Sport. 2006;**16**:83–92. doi:10.1111/j.1600-0838.2006.00528.x

26 Meeuwisse W, H MD P, Tyreman H, *et al.* A Dynamic Model of Etiology in Sport Injury:

The Recursive Nature of Risk and Causation. *Clin J Sport Med* 2007;**17**:215–9. doi:10.1097/JSM.0b013e3180592a48

27 MIRWALD RL, G. BAXTER-JONES AD, BAILEY DA, *et al.* An assessment of maturity from anthropometric measurements. *Med Sci Sport Exerc* 2002;**34**:689–94. doi:10.1097/00005768-200204000-00020

28 Khamis HJ, Roche AF. Predicting adult stature without using skeletal age: the Khamis-Roche method. Pediatrics. 1994;**94**:504–7. doi:10.1016/S0740-624X(98)90020-X

29 Silventoinen K, Pke M, Tynelius P. Muscle Strength and Body Size and Later Cerebrovascular and Coronary Heart Disease Maturity Status and Injury Risk in Youth Soccer Players. *Sport Med* 2010;**20**:131–5. doi:10.1136/bmj.b490.Objective

30 Fourchet F, Horobeanu C, Loepelt H, *et al.* Foot, Ankle, and Lower Leg Injuries in Young Male Track and Field Athletes. *Int J Athl Ther Train* 2011;**16**:19–23 5p. doi:10.1123/ijatt.16.3.19

31 Swain M, Kamper SJ, Maher CG, *et al.* Relationship between growth, maturation and musculoskeletal conditions in adolescents: a systematic review. *Br J Sports Med* 2018;:bjsports-2017-098418. doi:10.1136/bjsports-2017-098418

32 Müller L, Hildebrandt C, Müller E, *et al.* Long-Term athletic development in youth alpine ski racing: The effect of physical fitness, ski racing technique, anthropometrics and biological maturity status on injuries. *Front Physiol* 2017;**8**. doi:10.3389/fphys.2017.00656

33 Vanderlei FM, Vanderlei LCM, Bastos FN, *et al.* Characteristics and associated factors with sports injuries among children and adolescents. *Brazilian J Phys Ther* 2014;**18**:530–7. doi:10.1590/bjpt-rbf.2014.0059

34 Müller L. Müller EHCKK& RC. Die Erhebung des biologischen Entwicklungsstandes fur

die Talentselektion - welche Methode eignet sich? [The assessment of biological maturation for talent selection - which method can be used?]. *Sport Sport* 2015;**29**:56–63.

35 Bergeron MF, Mountjoy M, Armstrong N, *et al.* International Olympic Committee consensus statement on youth athletic development. *Br J Sports Med* 2015;**49**:843–51. doi:10.1136/bjsports-2015-094962

36 Kemper GLJ, Van Der Sluis A, Brink MS, *et al.* Anthropometric Injury Risk Factors in Elite-standard Youth Soccer. *Int J Sports Med* 2015;**36**:1112–7. doi:10.1055/s-0035-1555778

37 Backous DD, Friedl KE, Smith NJ, *et al.* Soccer Injuries and Their Relation to Physical Maturity. *Am J Dis Child* 1988;**142**:839–42. doi:10.1001/archpedi.1988.02150080045019

38 Malina RM, Morano PJ, Barron M, *et al.* Incidence and player risk factors for injury in youth football. *Clin J Sport Med* 2006;**16**:214–22. doi:10.1097/00042752-200605000-00005

39 Musch J, Grondin S. Unequal Competition as an Impediment to Personal Development: A Review of the Relative Age Effect in Sport. *Dev Rev* 2001;**21**:147–67. doi:10.1006/drev.2000.0516

40 Baxter-Jones ADG. Growth and Development of Young Athletes: Should Competition Levels be Age Related? *Sport Med* 1995;**20**:59–64. doi:10.2165/00007256-199520020-00001

41 Khosla T. Unfairness of certain events in the Olympic games. *Br Med J* 1968;**4**:111–3. doi:10.1136/bmj.4.5623.111

42 Beunen GP, Malina RM, Van't Hof MA, *et al. Adolescent Growth and Motor Performance*. 1988.

43 Philippaerts RM, Vaeyens R, Janssens M, *et al.* The relationship between peak height velocity and physical performance in youth soccer players. *J Sports Sci* 2006;**24**:221–30. doi:10.1080/02640410500189371

44 Malina RM, Bouchard C, Bar-Or O. Growth, maturation, and physical activity. *Growth, Matur Phys Perform* 2004;:1–17.

45 Mueller L, Hildebrandt C, Mueller E, *et al.* Injuries and illnesses in a cohort of elite youth alpine ski racers and the influence of biological maturity and relative age: a two-season prospective study. *Open Access J Sport Med* 2017;**Volume 8**:113–22. doi:10.2147/OAJSM.S133811

46 Malina RM, Rogol AD, Cumming SP, *et al.* Biological maturation of youth athletes: assessment and implications. *Br J Sports Med* 2015;**49**:852–9. doi:10.1136/bjsports-2015-094623

47 Theisen D, Malisoux L, Seil R, *et al.* : Injuries in Youth Sports: Epidemiology, Risk Factors and Prevention. *Dtsch Z Sportmed* 2014;**65**:S248-252.http://www.zeitschrift-sportmedizin.de/artikel-online/archiv-2014/heft-9/injuries-in-youth-sports-epidemiology-risk-factors-and-prevention/

48 Bittencourt NFN, Meeuwisse WH, Mendonça LD, *et al.* Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition—narrative review and new concept. *Br J Sports Med* 2016;**50**:1309–14. doi:10.1136/bjsports-2015-095850

CONTRIBUTORSHIP STATEMENT: AR designed and developed the research question and wrote the original version of the manuscript as part of his doctoral thesis. EW (doctoral supervisor) reviewed, designed and provided expertise to the study. AJ (doctoral committee member) was involved in study design. AF supervised and provided expertise with respect to the data analyses. VR, SP, and RV (doctoral committee member) reviewed and provided expertise to the study. All authors have contributed to and edited the manuscript and have approved the final manuscript.

FUNDING: This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

COMPETING INTERESTS: None declared.

Ethics approval: The study received ethical approval by the Anti- Doping Lab Qatar

DATA SHARING STATEMENT: No additional data are available

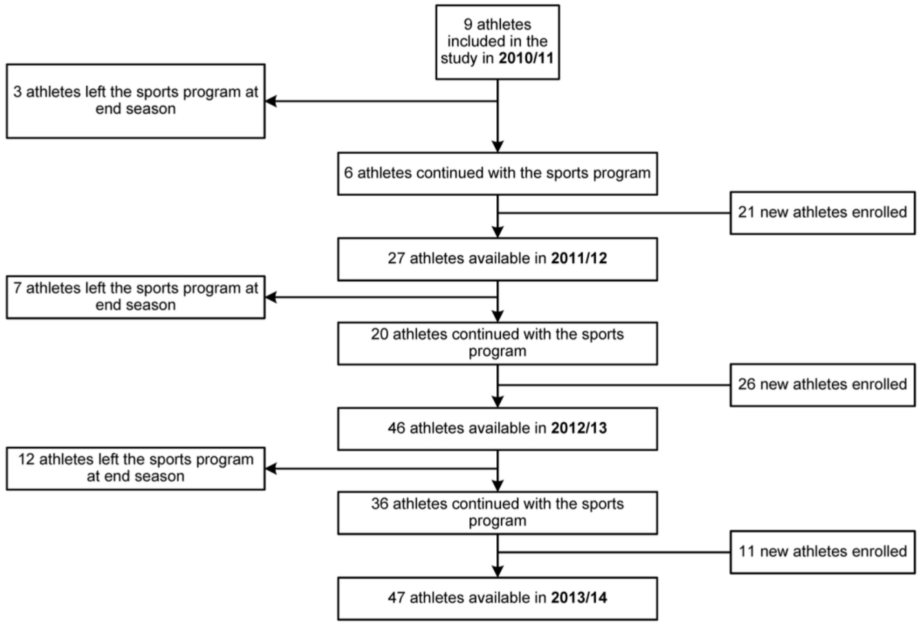

Figure 1. Flowchart describing the inclusion and flow of participants throughout the study

135x89mm (300 x 300 DPI)

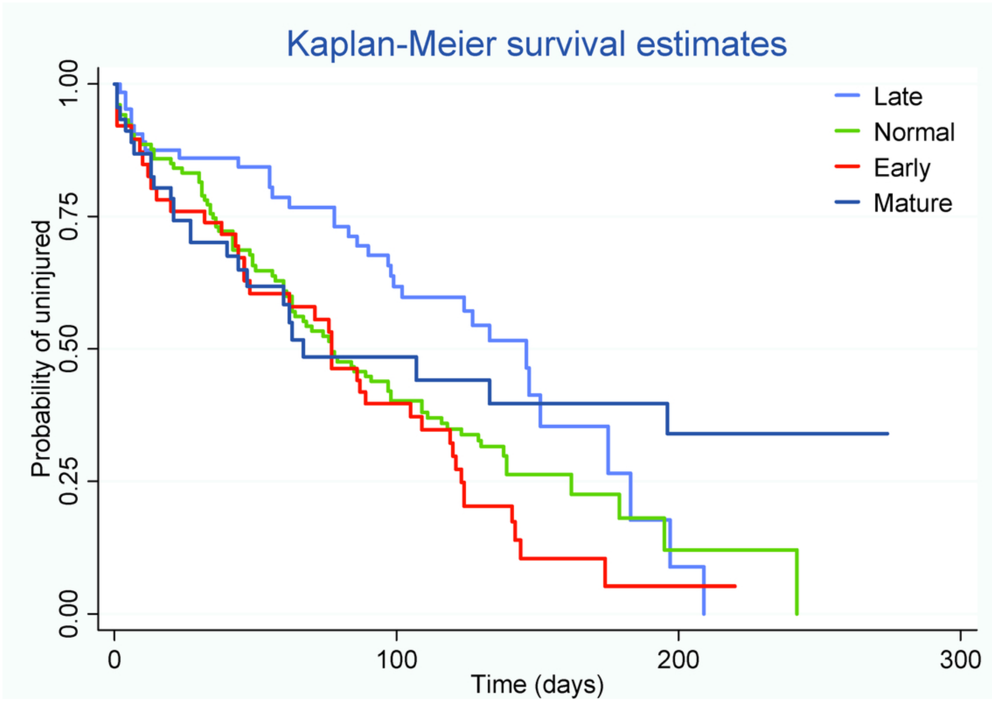

Figure 2. Kaplan-Meier survival analysis of injuries in relation to different skeletal age (SA) maturity status

96x67mm (300 x 300 DPI)

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Page 1 and Page 2.
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Pages 2 and 3.
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Pages 4.
Objectives	3	**State specific objectives, including any prespecified hypotheses**	Pages 4 and 5.
Methods			
Study design	4	Present key elements of study design early in the paper	Page 5, line of methods 82
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 5.
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Pages 5 and 6. Figure 1.
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	On pages 6, 7 and 8. Definition and data collection of outcome variables were given.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	On Pages 7 and 8.
Bias	9	Describe any efforts to address potential sources of bias	On Page 8.
Study size	10	Explain how the study size was arrived at	Every available athlete was included in our study.
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 5.

Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Pages 8.
		(*b*) Describe any methods used to examine subgroups and interactions	Pages 5 and 6
		(*c*) Explain how missing data were addressed	Not applicable
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	Not applicable
		(*e*) Describe any sensitivity analyses	Not applicable
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—e.g. numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	All participants eligible completed the study. Pages 6-7
		(b) Give reasons for non-participation at each stage	Not applicable
		(c) Consider use of a flow diagram	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (e.g. demographic, clinical, social) and information on exposures and potential confounders	Table 1
		(b) Indicate number of participants with missing data for each variable of interest	(Not applicable)
Outcome data	15*	Report numbers of outcome events or summary measures	Page 7 and page 8
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Table 1.
		(*b*) Report category boundaries when continuous variables were categorized	Not applicable
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not applicable
Other analyses	17	Report other analyses done—e.g. analyses of subgroups and interactions, and sensitivity analyses	Figure 2. different maturity level compared.
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 10.
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 13.
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 13.
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 13.
Other information			

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Not applicable

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Sports Injuries Aligned to Predicted Mature Height in Highly Trained Middle-Eastern Youth Athletes: A Cohort study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-023284.R2
Article Type:	Research
Date Submitted by the Author:	11-Jan-2019
Complete List of Authors:	Rejeb, Abdallah; Aspetar Qatar Orthopaedic and Sports Medicine Hospital, Aspire Academy Sports Medicine Center; Universiteit Gent Faculteit Geneeskunde en Gezondheidswetenschappen, Rehabilitation Sciences and Physiotherapie Johnson, Amanda; Aspetar Qatar Orthopaedic and Sports Medicine Hospital, Aspire Academy Sports Medicine Center Farooq, Abdulaziz; Aspetar, Orthopaedic and Sports Medicine Department, Athlete Health and Performance Research Verrelest, Ruth ; Universiteit Gent Faculteit Geneeskunde en Gezondheidswetenschappen, Rehabilitation Sciences and Physiotherapie Pullinger, Samuel; ASPIRE Academy for Sports Excellence, Sports Sciences Vaeyens, Roel ; Universiteit Gent Faculteit Geneeskunde en Gezondheidswetenschappen, Department of movement and Sports Sciences Witvrouw, Erik; Universiteit Gent Faculteit Geneeskunde en Gezondheidswetenschappen, Rehabilitation Sciences and Physiotherapy
Primary Subject Heading:	Sports and exercise medicine
Secondary Subject Heading:	Paediatrics, Evidence based practice
Keywords:	Youth, Biological maturation, Skeletal age, Anthropometrics, Sports injury, Mature height

Sports Injuries Aligned to Predicted Mature Height in Highly Trained Middle-Eastern Youth Athletes: A Cohort study

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Manuscript word count = 3201

ABSTRACT (296/300 words)

OBJECTIVES: To investigate the association of maturity status with injury incidence in Middle-Eastern youth athletes.

DESIGN: Prospective cohort study

SETTING: Four consecutive seasons (2010 to 2014), Aspire Academy, Qatar.

PARICIPANTS: Male athletes (age range: 11–18 y) representing four disciplines enrolled and grouped into two categories: individual sports and racquet sports.

OUTCOME MEASURES: Injury data collected over four seasons. Athletes' anthropometric characteristics assessed to calculate APHV. Predicted mature heights (PMHs) collected and categorized into four quartiles. Athletes had wrist and hand radiographs for assessment of skeletal age (SA). Early and late maturers with an SA of >1 y older or younger than their chronological age (CA).

RESULTS: For the sample (n = 67) across all groups, 43 (64%) athletes had one or more injuries: total of 212 injuries, 4.9 injuries per athlete across study. Survival analysis of maturity status using SA found early maturing athletes had two-fold greater injury risk compared to late maturers ([HR]; 2.04, 95% CI 1.15–3.61, P = 0.015). PMH associated with injury risk (HR 1.05, 95% CI 1.01–1.08, P = 0.006).

Athletes in 4th quartile (≥ 184 cm) had up to 2-fold injury risk (HR 2.41, 95% CI 1.42–4.08, P = 0.001). Racquet and individual sports involved similar injury risk (HR 1.14, 95% CI 0.86–1.52, P = 0.37).

CONCLUSION: SA early maturity and PMH gradient were significant predictors of injury in youths.

STRENGTHS AND LIMITATIONS OF THE STUDY

- First longitudinal study to assess anthropometric characteristics and biological maturity status as injury risk factors in Middle-Eastern athletes.
- Participants were highly trained adolescent athletes.
- Measurement of maturity and growth were at moderate-to-high risk of bias.
- SA has major limitations in expense and minimal radiation and lack of knowledgeable staff for assessment and interpretation of results.

INTRODUCTION

The range of somatic and biological maturity in individuals of the same chronological age (CA) is large [1]. Such observations are derived from correlational and multivariate studies that compare young individuals of the same age who are at both extremes of the maturity range [2]. Therefore, the assessment of maturity is an important consideration when dealing with adolescent athletes on a longitudinal basis. Further, understanding the cause of disease and injury is vital in predicting and preventing injury [3].

In young athletes, the demands of their chosen sport are superimposed on normal growth and maturation. A literature review revealed that there is a greater susceptibility to injury during certain periods of growth [4–6]. Indeed, the association between an increased prevalence of injuries and the adolescent growth spurt has long been recognized [7–9]. A recent study analysis [10] on adolescent soccer players revealed greater risk of injury with players within age at peak height velocity (APHV) in comparison with the players before and after APHV. Mismatched rapid growth in the long bones relative to muscular lengthening may disrupt structure, neuromuscular function, and physical performance [11].

Deehan et al. [12], state that an increased participation in sports predisposes the immature skeleton to injury. Furthermore, participation in high intensity sport entails an inherent risk of sports-related injuries, and this is heightened at various stages of growth and maturation [13]. Maturation induces profound changes in the skeletal, neuromuscular, and tendinous systems of young athletes [14] and mismatches in biological maturity may create competitive inequality and increase the risk of injury [15]. Le Gall et al. [16], further point out that injury rates generally increase with increasing CA. However, CA is a poor indicator of biological maturity [17]; moreover, Ardern et al. [18], report that chronological age alone is an unreliable indicator of skeletal maturity. Skeletal age (SA) is generally accepted as the most accurate method of assessing biological maturity [6,19], by identifying critical periods of development; it also offers a rational method for monitored age-specific training. Before initiating any program for mitigating sports injuries, the magnitude of the problem must be identified and the extent of the injury defined in terms of incidence and severity [20].

A number of studies have been conducted involving injuries in adolescent footballers; conversely, few studies have focused on injuries in non-footballer adolescent athletes in high performance sporting environments [21]. Studies of anthropometric characteristics and biological maturity status as injury risk factors in Middle-Eastern youths are also limited, highlighting the need for more research in this area. Therefore, the purpose of the present study was to investigate injury incidence according to biological maturity using two outcome measures (SA and PHV) in highly trained youth athletes based at a Middle Eastern Sports Academy.

METHODS

Sixty-seven highly trained adolescent athletes (age range 11–18 y) representing athletics and racquet sports (table tennis and squash) from a Middle Eastern sports school were included in this four-year study. A prospective, longitudinal cohort design was used and included separate observation periods over four consecutive seasons (2010–2011, 2011–2012, 2012–2013, and 2013–2014), i.e., school years, which lasted from the beginning of September until the end of June (~40 weeks). Participant maturity assessments included both anthropometric measurements, collected three times a season, and SA assessments using Fels method completed once, at the start of every season. Medical screening was performed at the beginning of each season to determine health and injury status. All selected athletes had clearance from a physician to participate in their respective sport. Written informed consent was sought and obtained from parents and assent from all participants. The study was part of a general sports science provision to the sports academy, and all procedures were reviewed and granted by the Institutional Review Board (IRB) for Human Subjects and conformed to the recommendations of the Declaration of Helsinki.

Participants

Figure 1 shows the flow of participants in the study over consecutive seasons. A total of four sporting disciplines were analysed, grouped into two categories: athletics and fencing and racquet sports (squash and table tennis). This classification was based on specific sport characteristics and injury risk [22,23]. Inclusion criteria were as follows: (1) the athlete had to be enrolled in the sports school during at least one full school year; (2) athletes with injuries in previous seasons were not excluded from this study, but injuries present at the beginning of the observation period were not included in statistical analyses; and (3) injuries that were not sustained in the context of the sports program (e.g. recreational activities) or data related to sickness or other general medical conditions were not used for further analysis.

<<<Insert Figure 1 here>>>

Injury definition and data collection

An Injury was defined as any physical complaint, which occurred during sports training, strength and conditioning training or during competition. Injuries were divided into time-loss (TL) injuries and no time-loss (NTL) injuries. A clinical examination and/or treatment of an athlete which did not result in a full training session or competition being missed was described as a complaint with NTL injury. A clinical examination and/or treatment of an athlete resulting in a training session or competition being missed the following day(s) was labelled as a TL injury [23]. A traumatic injury was defined as any injury resulting from a specific and identifiable mechanism, including contact and non-contact circumstances with acute onset. Overuse injuries were defined as injuries resulting from insidious onset without a recognizable mechanism. Injury severity was defined, based on days of absence from usual sport participation, as slight (1 d or less), minimal (2–3 d), mild (4–7 d), moderately serious (8–28 d), serious (>28 d up to 6 months) or long-term (>6 months) in accordance with [24].

All injuries were collected by a physical therapist (AR) with experience of working within youth sport. Data from medical records were used to document all sports related injuries during the study. Each sporting discipline had a dedicated full-time physiotherapist and a full-time employed medical doctor at the sports academy. The medical record used an injury reporting system based upon the football injury reporting system [25] and the Sport Medicine Diagnostic Coding System [26]. Information was gathered concerning all injuries related to sports activity, including several related variables (e.g. type, location, affected structure, mechanism [acute vs. overuse], time loss, severity, and date of injury).

Somatic maturation and anthropometric measurements

Anthropometric measurements were initially carried out on all participants on a three monthly basis along with an estimation of the age at peak height velocity (APHV) as a relative indicator of somatic maturity and representing the time of maximum growth in stature during adolescence using Mirwald method [27] for the prediction of growth [1]. APHV was calculated from the first measurement recorded. To ensure that the outcome measures remained consistent and reliable, every effort was made to ensure that measurements were taken at approximately the same time of the season. Measurements were collected by qualified practitioners from the International

Society for the Advancement of Kinanthropometry (ISAK) and included stretch stature (± 0.1 cm Holtain Limited, Crosswell, UK).

The predicted mature height (PMH) of all participants were collected and categorized into four PMH quartiles (Q1–Q4: Q1 < 176 cm; 176 cm ≤ Q2 < 180 cm; 180 cm ≤ Q3 < 184 cm; Q4 ≥ 184 cm). The athletes were then divided into three maturity groups (late, normal, or early maturing) based on the mean ± 1.0 year of the APHV of the total sample (late, APHV > mean + 1.0 y; normal, APHV within mean ± 1.0 y; early, APHV < mean – 1.0 y). Years from peak height velocity (maturity offset value: CA – maturity offset) was calculated by subtracting the CA at the date of injury from the age at estimated peak height velocity.

Skeletal maturation assessment

Each year athletes were required to have a radiograph of the left wrist and hand, a convenient area to examine, and a more accurate method for the assessment of SA [11], using the Fels method [6,28] which has an advantage over other methods [29]. Maturity status, defined by the difference between CA and SA was calculated and classified into four categories: late, normal, early, and mature athletes. Late referred to an SA that was younger than CA by more than 1.0 y, athletes with a normal pattern of maturity had an SA that was within 1.0 y of CA, early referred to an SA that was older than CA by more than 1.0 y, and the closure of growth plate determine skeletally mature athletes.

Statistical Analysis

Data were analysed using statistical software (Stata Corporation, College Station, Texas). Descriptive statistics were presented as frequencies and proportions (%), and incidence rates were expressed as the number of injuries/number of registered athletes. To examine the role of growth status and maturity with the onset of injuries, a univariate Cox regression survival analysis was performed after accounting for repeated visits of athletes over the four seasons. Hazard ratios

(HR) with 95% confidence intervals (CIs) were reported for each factor. Kaplan-Meier curves were plotted for SA groups and time to injury over a season. Where appropriate, 95% CIs are presented. The alpha level of significance was set at 5%.

Patient and public involvement statement

Patients and public were not involved in the analysis of this study.

RESULTS

Throughout the four-year seasons study period, 67 athletes were enrolled representing 151 athletic seasons. Table 1 presents the anthropometric characteristics of participants and their maturity status. From these participants, 43 (64%) reported one or more injuries adding up to 212 injuries in total., The injury rate observed per registered athlete amounted to 4.9 injuries over the course of four seasons.

Table 1. Anthropometric characteristics (mean ± SD) of participants according to maturity status

	Late	Normal	Early
	(n = 4, 6.0%)	(n = 59, 88.1%)	(n = 4, 6.0%)
CA (years)	13.3 ± 1.1	12.3 ± 1.0	12.1 ± 0.5
Years from PHV	-2.4 ± 1.2	-1.6 ± 1.1	-0.1 ± 0.9
APHV (years)	15.8 ± 1.5	13.9 ± 0.5	12.2 ± 0.9
PMH (cm)	181.6 ± 17.1	179.4 ± 4.9	188.4 ± 3.5
% PMH (%)	85.0 ± 3.0	85.0 ± 4.0	90.0 ± 4.0
SA (years)	11.8 ± 0.5	12.8 ± 1.5	12.7 ± 1.8

CA: chronological age; APHV: age at peak height velocity; PMH: predicted mature height; SA: skeletal age; SD: standard deviation

Skeletal age: maturity status distribution and injury risk

Among all participants (n = 67), 4% were classified as late maturers, 33% as normal, 41% as early and 22% as skeletally mature. The overall injury free survival analysis of maturity status using SA assessment indicated that early maturing athletes had a two-fold higher risk of injury over a season compared to late maturing athletes (HR 2.04, 95% CI 1.15–3.61, P = 0.015),

(Figure 2). There was a trend that early maturing athletes had a greater risk of injury over a season compared to normal athletes (HR 1.62, 95% CI 0.99–2.65, P = 0.053), but this was only marginally significant. However, injury risk among late and fully mature athletes did not differ from normal maturers.

<<<<Insert Figure 2 Here >>>>

Somatic maturation and anthropometric measurements: distribution and injury risk

Using anthropometric measurements, among all participants (n = 67), 6.0% were classified as late maturing, 85.8% as normal, and 6.0% as early. Classification of participant maturity status (late, normal, and early) according to age at PHV (APHV) was not significantly associated with overall injury incidence in this cohort of highly trained Middle-Eastern youth athletes. Older PHVs were marginally associated with higher injury risk, but this was not statistically significant (HR 1.11, 95% CI 0.99–1.23, P = 0.067).

Both PMH (cm), and %PMH were found to be associated with injury risk (HR 1.05, 95% CI 1.01–1.08, P = 0.006, and HR 1.03, 95% CI 1.00–1.06, P = 0.026), respectively. When compared to participants in the 1st quartile for PMH (<176), athletes in the 4th quartile (≥184 cm) had a two and half times greater risk of injury (HR 2.41, 95% CI 1.42–4.08, P = 0.001) over a season.

No significant differences were observed in the injury risk between racquet sports (n = 30) and individual sports athletes (n = 37; HR 1.14, 95% CI, 0.86–1.52, P = 0.37).

DISCUSSION

The present investigation was carried out to examine injury incidence according to maturity status. Biological maturity status and height gradient play a significant role in injury risk profiles of highly trained youth athletes. The results of the current study show that athletes maturing at a younger age are at significantly greater risk of injury, more than two-fold, compared to their later maturing counterparts. Taller athletes were also found to be significantly more at risk of injury.

There is limited and contrasting evidence on the relationship between maturity and injury in youth sports [10,30,31]. In this study, SA maturity (Fels method) showed that early maturing athletes had twice the risk of injury over a season compared to late maturing athletes. This finding is consistent with previous study [6], that described that early maturing athletes are significantly more at risk of injury than late or normally maturing athletes. A possible explanation could be that youth players with higher engagement and performance advantages are often associated with early maturation, usually transient during adolescence, and maybe reversed in early adulthood [16]

However, our study results were inconsistent with other study [30] on youth athletes, in which late maturing athletes have a higher injury rate compared to their earlier maturing counterparts. A plausible explanation could be that Fourchet et al. [30], examined anthropometric data collected from a track and field cohort for their findings, while our study resulted from maturity status derived from bone age but with no substantial association from APHV.

In the present study, no significant association was observed between APHV and injury risk (HR 0.90, 95% CI 0.74–1.11, P = 0.329), which is inconsistent with recent data on youth alpine ski racing [32] and other studies on talented Dutch and English youth soccer players [6,33] which show a heightened period of risk around the time of peak height velocity. An explanation of these discrepancies could be that our study cohort was not large enough, as the APHV method appears to be useful in youth talent selection and injury prevention programs because it can be easily applied in a large cohort of young athletes [34].

PMH and %PMH at a given age are minimally invasive, feasibly practical indicators of somatic maturation [17,35], especially if mature height can be assessed without an estimate of SA [28]. In this study, the PMH and %PMH revealed that both indicators were associated with injury risk (HR 1.05, 95% CI 1.01–1.08, P = 0.006), and HR 1.03, 95% CI 1.00–1.06, P = 0.026), respectively. When compared to participants in the 1st quartile for PMH (<176), athletes in the 4th quartile (≥184 cm) had two and a half times greater risk of injury (HR 2.41, 95% CI 1.42–4.08, P = 0.001). The present results are partly in line with previous studies on other sports. Johnson et al. [6], showed that gains in height in youth footballers over a season were associated with an increased number of injuries. The study of Kemper et al. [36], on elite youth soccer players with growth rates of at least 0.6 cm/month showed a higher risk for injury. In a different study on soccer athletes, it was found that the tallest boys had the highest incidence of injury [37]. However, these findings and those of the present study are not in line with a study on youth football players [38], in which injured and non-injured players did not differ in percentage of mature height. An explanation could be that the definition of reportable injury in the methods of the study, which considered only time loss injuries, did not capture the full spectrum of injuries and therefore overlooked other injuries with insidious onset e.g. growth conditions.

The results of this study have some important practical implications. Malina et al. [2], advocate the documentation of anthropometric characteristics, biological maturity, and physical fitness parameters as crucial aids in the prevention of injury. Noninvasive methods for estimating maturity status may allow youth programs to match players using maturity status rather than CA, and thus equalize competition to some extent. An unequal competition is regarded as an impediment to personal development [39]. Furthermore, it has been suggested that there is an overwhelming bias in sport favoring taller athletes [40], and data on Olympic medal winners show that many running and jumping events are seriously biased in favor of the very tall [41].

When examining the classification resulting from SA of late (4%), normal (33%), early (41%), and skeletally mature athletes (22%), the under-representation of late and preponderance of early maturing athletes in this cohort is consistent with observations for male youth athletes in several sports including soccer and alpine ski racing [10,19,32]. However, these results and those of the present study are not in line with the study of Johnson et al. [6], on schoolboy footballers, in which two thirds of their players fall within the normal maturity category. Moreover, Le Gall et al. [16], classify only 12.0% as late maturers, 63.5% as normal maturers, and 24.5% as early maturers. These discrepancies are believed to be due to differences in selection policies and talent identification policies (physical, technical, and tactical skills) of varying elite development centers. Several studies point out that athletes who are more advanced in their biological maturity perform better than their later maturing peers and have a better chance of being selected [42–44]. Youth sport is highly selective, with a maturity-associated selection/exclusion process [35].

Implications and concepts for prevention

The findings in this study have several implications for youth athletes. First, our data suggests that adolescent athletes might be identified and selected with a preference for youths with advanced maturity. Such selection strategies which favor early maturers entail significant risks of injury. Accordingly, those involved in the selection and development of young athletes should be cognizant of temporary changes in motor control that may occur during these periods [45], consider maturity status, develop appropriate training programs to optimize training adaptation, design injury prevention plans to minimize activity related injury risk, and mitigate long term youth injury consequences.

Limitations of the current study should be noted. First, biological maturation methods have inherent limitations when applied to youth athletes and need to be applied with caution. Although SA is a gold standard indicator of maturation, it has major limitations in expense and minimal radiation and lack of knowledgeable staff for assessment protocols and the interpretation of results [46]. Although our sample size is small, we have a follow-up over four seasons. Another limitation, we had no data on training or competition exposure, which reduces the comparability with other studies reporting injury incidence.

It must also be remembered that, except for accidents, a sports injury can rarely be ascribed to a single factor, but rather to an association of causes or circumstances and the interaction among a web of determinants [47,48].

CONCLUSIONS

The findings of the present study showed that maturity status plus PMH and %PMH are associated with injury in individual and racquet sports but no association has been established between APHV and injury. As SA varies individually in rate and timing, and mismatches in maturity may create competitive inequality and increase injury incidence, it is suggested that biological maturity should be considered during training to help prevent injury. Given the peculiarity of youth athletes it is important to optimize the planning of training activities to further improve the understanding of the link between training, growth, and injury.

Figure legends

<<<Figure 1. Flowchart describing the inclusion and flow of participants throughout the study >>>

<<<Figure 2. Kaplan-Meier survival analysis of injuries in relation to different skeletal age (SA) maturity status >>>

REFERENCES

1 Iuliano-Burns S, Mirwald RL, Bailey DA. Timing and magnitude of peak height velocity and peak tissue velocities for early, average, and late maturing boys and girls. *Am J Hum Biol* 2001;**13**:1–8. doi:10.1002/1520-6300(200101/02)13:1<1::AID-AJHB1000>3.0.CO;2-S

2 Malina RM, Cumming SP, Morano PJ, *et al.* Maturity status of youth football players: A noninvasive estimate. *Med Sci Sports Exerc* 2005;**37**:1044–52. doi:10.1249/01.mss.0000171622.45134.cb

3 Meeuwisse W. Assessing Causation in Sport Injury: A Multifactorial Model. *Clin J Sport Med* 1994;**4**:166–70. doi:10.1097/00042752-199407000-00004

4 Krivickas LS, Feinberg JH. Lower extremity injuries in college athletes: Relation between ligamentous laxity and lower extremity muscle tightness. *Arch Phys Med Rehabil* 1996;**77**:1139–43. doi:10.1016/S0003-9993(96)90137-9

5 Aicardi G, Vignolo M, Milani S, *et al.* Assessment of skeletal maturity of the hand-wrist and knee: A comparison among methods. *Am J Hum Biol* 2000;**12**:610–5. doi:10.1002/1520-6300(200009/10)12:5<610::AID-AJHB5>3.0.CO;2-D

6 Johnson A, Doherty PJ, Freemont A. Investigation of growth, development, and factors associated with injury in elite schoolboy footballers: prospective study. *Bmj* 2009;**338**:b490–b490. doi:10.1136/bmj.b490

7 Peterson HA. *Epiphyseal growth plate fractures*. 2007. doi:10.1007/978-3-540-33802-4

8 Bailey DA, Wedge JH, McCulloch RG, *et al.* Epidemiology of fractures of the distal end of the radius in children as associated with growth. *J Bone Jt SurgAm* 1989;**71**:1225–31.http://www.ncbi.nlm.nih.gov/pubmed/2777851

9 Leppänen M, Pasanen K, Clarsen B, *et al.* Overuse injuries are prevalent in children's competitive football: a prospective study using the OSTRC Overuse Injury Questionnaire. *Br J Sports Med* 2018;:bjsports-2018-099218. doi:10.1136/bjsports-2018-099218

10 Materne O, Farooq A, Johnson A, *et al.* Relationship between injuries and somatic maturation in highly trained youth soccer players. *Int Res Sci Soccer II* 2016;:182–92.https://books.google.com/books?hl=en&lr=&id=w8DMCgAAQBAJ&oi=fnd&pg=PA182&dq=Relationship+between+injuries+and+somatic+maturation+in+highly+trained+youth+soccer+players&ots=6D7Xy7rLzj&sig=ywUDNrV1u4pMrJlBN3wERj1u93M%5Cnhttp://s3.

amazonaws.com/academia.edu.

11 Lloyd RS, Oliver JL, Faigenbaum AD, *et al.* Chronological Age vs. Biological Maturation. *J Strength Cond Res* 2014;**28**:1454–64. doi:10.1519/JSC.0000000000000391

12 Deehan DJ, Bell K, McCaskie AW. Adolescent musculoskeletal injuries in a football academy. *J Bone Jt Surg - Br Vol* 2007;**89–B**:5–8. doi:10.1302/0301-620X.89B1.18427

13 Read P, Oliver JL, De Ste Croix MBA, *et al.* Injury Risk Factors in Male Youth Soccer Players. *Strength Cond J* 2015;**37**:1–7. doi:10.1519/SSC.0000000000000171

14 Huey K, Robinson MM, Wiesinger H-P, *et al.* Imbalances in the Development of Muscle and Tendon as Risk Factor for Tendinopathies in Youth Athletes: A Review of Current Evidence and Concepts of Prevention. 2017;**8**:1–18. doi:10.3389/fphys.2017.00987

15 Cumming SP, Brown DJ, Mitchell S, *et al.* Premier League academy soccer players' experiences of competing in a tournament bio-banded for biological maturation. J. Sports Sci. 2017;:1–9. doi:10.1080/02640414.2017.1340656

16 Le Gall F, Carling C, Reilly T. Biological maturity and injury in elite youth football. *Scand J Med Sci Sport* 2007;**17**:564–72. doi:10.1111/j.1600-0838.2006.00594.x

17 Beunen GP, Rogol AD, Malina RM. Indicators of biological maturation and secular changes in biological maturation. Food Nutr. Bull. 2006;**27**. doi:10.1177/156482650902000307

18 Ardern CL, Ekås G, Grindem H, *et al.* 2018 International Olympic Committee consensus statement on prevention, diagnosis and management of paediatric anterior cruciate ligament (ACL) injuries. *Knee Surgery, Sport Traumatol Arthrosc* 2018;**0**:1–17. doi:10.1007/s00167-018-4865-y

19 Malina RM. Early sport specialization: Roots, effectiveness, risks. *Curr Sports Med Rep*

2010;**9**:364–71. doi:10.1249/JSR.0b013e3181fe3166

20 Leppänen M, Lapinleimu H, Lehtonen L, *et al.* Growth of extremely preterm infants born in 2001-2010. *Acta Paediatr Int J Paediatr* 2013;**102**:206–8. doi:10.1111/apa.12061

21 Steffen K. More data needed on injury risk among young elite athletes. *Br J Sports Med* 2010;**44**:485–9.http://search.ebscohost.com/login.aspx?direct=true&db=sph&AN=51172712&site=ehost-live

22 Rejeb A, Johnson A, Vaeyens R, *et al.* Compelling overuse injury incidence in youth multisport athletes. *Eur J Sport Sci* 2017;**17**:495–502. doi:10.1080/17461391.2016.1275820

23 Malisoux L, Frisch A, Urhausen A, *et al.* Injury incidence in a sports school during a 3-year follow-up. *Knee Surgery, Sport Traumatol Arthrosc* 2013;**21**:2895–900. doi:10.1007/s00167-012-2185-1

24 Timpka T, Alonso J-M, Jacobsson J, *et al.* Injury and illness definitions and data collection procedures for use in epidemiological studies in Athletics (track and field): Consensus statement. *Br J Sports Med* 2014;**48**:483–90. doi:10.1136/bjsports-2013-093241

25 Fuller CW, Ekstrand J, Junge A, *et al.* Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Scand. J. Med. Sci. Sport. 2006;**16**:83–92. doi:10.1111/j.1600-0838.2006.00528.x

26 Meeuwisse W, H MD P, Tyreman H, *et al.* A Dynamic Model of Etiology in Sport Injury: The Recursive Nature of Risk and Causation. *Clin J Sport Med* 2007;**17**:215–9. doi:10.1097/JSM.0b013e3180592a48

27 MIRWALD RL, G. BAXTER-JONES AD, BAILEY DA, *et al.* An assessment of maturity from anthropometric measurements. *Med Sci Sport Exerc* 2002;**34**:689–94. doi:10.1097/00005768-200204000-00020

28 Khamis HJ, Roche AF. Predicting adult stature without using skeletal age: the Khamis-Roche method. Pediatrics. 1994;**94**:504–7. doi:10.1016/S0740-624X(98)90020-X

29 Silventoinen K, Pke M, Tynelius P. Muscle Strength and Body Size and Later Cerebrovascular and Coronary Heart Disease Maturity Status and Injury Risk in Youth Soccer Players. *Sport Med* 2010;**20**:131–5. doi:10.1136/bmj.b490.Objective

30 Fourchet F, Horobeanu C, Loepelt H, *et al.* Foot, Ankle, and Lower Leg Injuries in Young Male Track and Field Athletes. *Int J Athl Ther Train* 2011;**16**:19–23 5p. doi:10.1123/ijatt.16.3.19

31 Swain M, Kamper SJ, Maher CG, *et al.* Relationship between growth, maturation and musculoskeletal conditions in adolescents: a systematic review. *Br J Sports Med* 2018;:bjsports-2017-098418. doi:10.1136/bjsports-2017-098418

32 Müller L, Hildebrandt C, Müller E, *et al.* Long-Term athletic development in youth alpine ski racing: The effect of physical fitness, ski racing technique, anthropometrics and biological maturity status on injuries. *Front Physiol* 2017;**8**. doi:10.3389/fphys.2017.00656

33 Vanderlei FM, Vanderlei LCM, Bastos FN, *et al.* Characteristics and associated factors with sports injuries among children and adolescents. *Brazilian J Phys Ther* 2014;**18**:530–7. doi:10.1590/bjpt-rbf.2014.0059

34 Müller L. Müller EHCKK& RC. Die Erhebung des biologischen Entwicklungsstandes fur die Talentselektion - welche Methode eignet sich? [The assessment of biological maturation for talent selection - which method can be used?]. *Sport Sport* 2015;**29**:56–63.

35 Bergeron MF, Mountjoy M, Armstrong N, *et al.* International Olympic Committee consensus statement on youth athletic development. *Br J Sports Med* 2015;**49**:843–51. doi:10.1136/bjsports-2015-094962

36 Kemper GLJ, Van Der Sluis A, Brink MS, *et al.* Anthropometric Injury Risk Factors in Elite-standard Youth Soccer. *Int J Sports Med* 2015;**36**:1112–7. doi:10.1055/s-0035-1555778

37 Backous DD, Friedl KE, Smith NJ, *et al.* Soccer Injuries and Their Relation to Physical Maturity. *Am J Dis Child* 1988;**142**:839–42. doi:10.1001/archpedi.1988.02150080045019

38 Malina RM, Morano PJ, Barron M, *et al.* Incidence and player risk factors for injury in youth football. *Clin J Sport Med* 2006;**16**:214–22. doi:10.1097/00042752-200605000-00005

39 Musch J, Grondin S. Unequal Competition as an Impediment to Personal Development: A Review of the Relative Age Effect in Sport. *Dev Rev* 2001;**21**:147–67. doi:10.1006/drev.2000.0516

40 Baxter-Jones ADG. Growth and Development of Young Athletes: Should Competition Levels be Age Related? *Sport Med* 1995;**20**:59–64. doi:10.2165/00007256-199520020-00001

41 Khosla T. Unfairness of certain events in the Olympic games. *Br Med J* 1968;**4**:111–3. doi:10.1136/bmj.4.5623.111

42 Beunen GP, Malina RM, Van't Hof MA, *et al. Adolescent Growth and Motor Performance*. 1988.

43 Philippaerts RM, Vaeyens R, Janssens M, *et al.* The relationship between peak height velocity and physical performance in youth soccer players. *J Sports Sci* 2006;**24**:221–30.

doi:10.1080/02640410500189371

44 Malina RM, Bouchard C, Bar-Or O. Growth, maturation, and physical activity. *Growth, Matur Phys Perform* 2004;:1–17.

45 Mueller L, Hildebrandt C, Mueller E, *et al.* Injuries and illnesses in a cohort of elite youth alpine ski racers and the influence of biological maturity and relative age: a two-season prospective study. *Open Access J Sport Med* 2017;**Volume 8**:113–22. doi:10.2147/OAJSM.S133811

46 Malina RM, Rogol AD, Cumming SP, *et al.* Biological maturation of youth athletes: assessment and implications. *Br J Sports Med* 2015;**49**:852–9. doi:10.1136/bjsports-2015-094623

47 Theisen D, Malisoux L, Seil R, *et al.* : Injuries in Youth Sports: Epidemiology, Risk Factors and Prevention. *Dtsch Z Sportmed* 2014;**65**:S248-252.http://www.zeitschrift-sportmedizin.de/artikel-online/archiv-2014/heft-9/injuries-in-youth-sports-epidemiology-risk-factors-and-prevention/

48 Bittencourt NFN, Meeuwisse WH, Mendonça LD, *et al.* Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition—narrative review and new concept. *Br J Sports Med* 2016;**50**:1309–14. doi:10.1136/bjsports-2015-095850

CONTRIBUTORSHIP STATEMENT: AR designed and developed the research question and wrote the original version of the manuscript as part of his doctoral thesis. EW (doctoral supervisor) reviewed, designed and provided expertise to the study. AJ (doctoral committee member) was involved in study design. AF supervised and provided expertise with respect to the data analyses. RVe, SP, and RVa (doctoral committee member) reviewed and provided expertise to the study. All authors have contributed to and edited the manuscript and have approved the final manuscript.

FUNDING: This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

COMPETING INTERESTS: None declared.

ETHICS APPROVAL: The study received ethical approval by the Anti- Doping Lab Qatar

DATA SHARING STATEMENT: No additional data are available

ACKNOWLEDGEMENTS: The publication of this article was funded by the Qatar National Library.

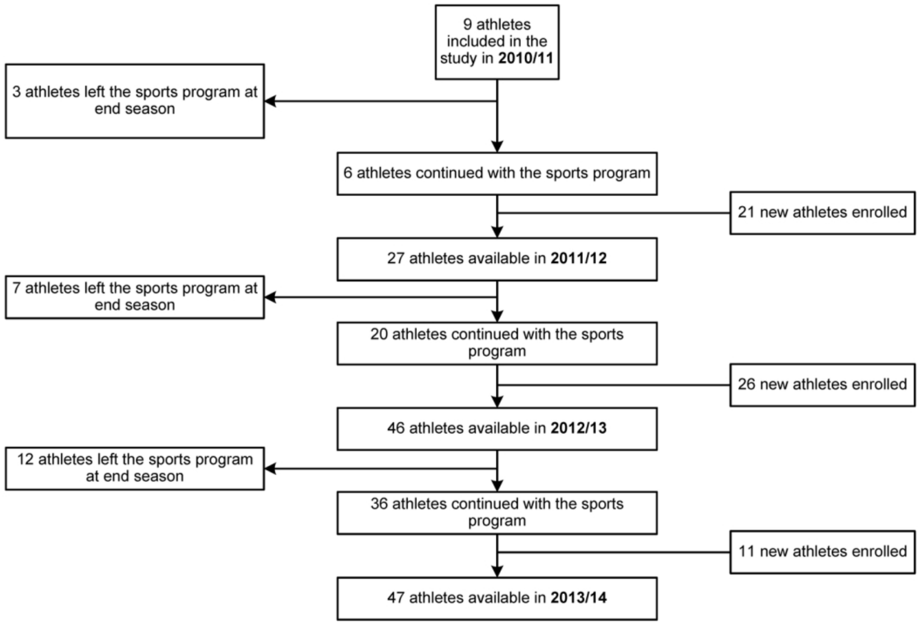

Figure 1. Flowchart describing the inclusion and flow of participants throughout the study

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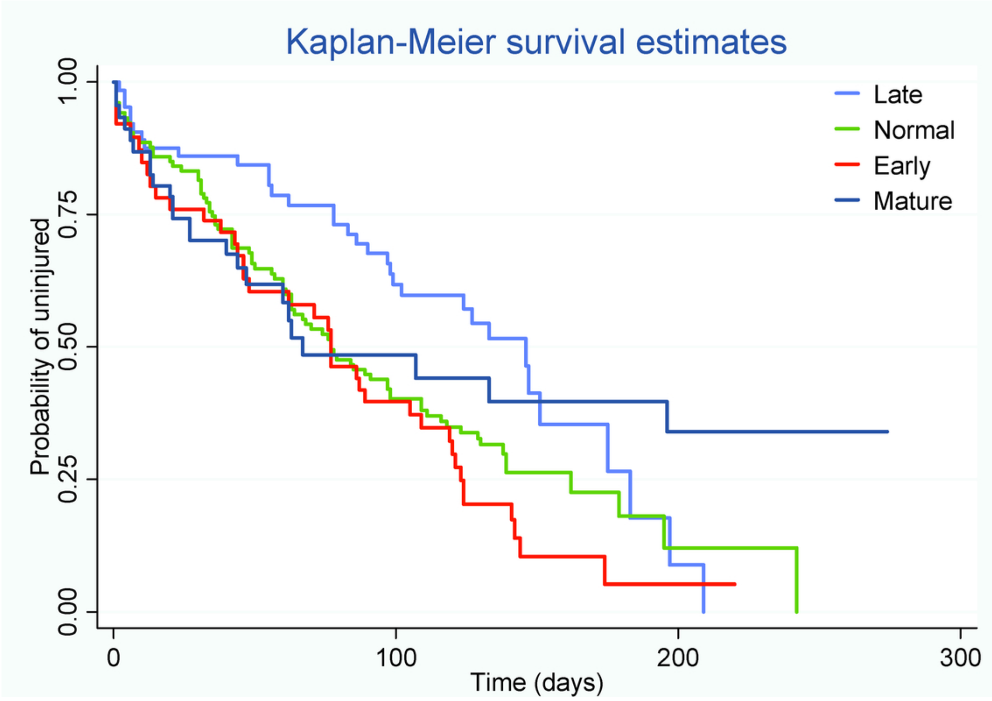

Figure 2. Kaplan-Meier survival analysis of injuries in relation to different skeletal age (SA) maturity status

96x67mm (300 x 300 DPI)

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Page 1 and Page 2.
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Pages 2 and 3.
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Pages 4.
Objectives	3	**State specific objectives, including any prespecified hypotheses**	Pages 4 and 5.
Methods			
Study design	4	Present key elements of study design early in the paper	Page 5, line of methods 86
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 5.
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Pages 5 and 6. Figure 1.
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	On pages 6, 7 and 8. Definition and data collection of outcome variables were given.
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	On Pages 7 and 8.
Bias	9	Describe any efforts to address potential sources of bias	On Page 8.
Study size	10	Explain how the study size was arrived at	Every available athlete was included in our study.
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 5.

Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Pages 8.
		(*b*) Describe any methods used to examine subgroups and interactions	Pages 5 and 6
		(*c*) Explain how missing data were addressed	Not applicable
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	Not applicable
		(*e*) Describe any sensitivity analyses	Not applicable
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—e.g. numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	All participants eligible completed the study. Pages 6-7
		(b) Give reasons for non-participation at each stage	Not applicable
		(c) Consider use of a flow diagram	Figure 1
Descriptive data	14*	(a) Give characteristics of study participants (e.g. demographic, clinical, social) and information on exposures and potential confounders	Table 1
		(b) Indicate number of participants with missing data for each variable of interest	(Not applicable)
Outcome data	15*	Report numbers of outcome events or summary measures	Page 7 and page 8
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Table 1.
		(*b*) Report category boundaries when continuous variables were categorized	Not applicable
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not applicable
Other analyses	17	Report other analyses done—e.g. analyses of subgroups and interactions, and sensitivity analyses	Figure 2. different maturity level compared.
Discussion			
Key results	18	Summarise key results with reference to study objectives	Pages 8-10.
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 13.
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 13.
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 13.
Other information			

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Not applicable

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.